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MAPS AND MAP-WORK

BY

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AUTHOR OF "MAP-READING"

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PREFACE

THE following chapters on the main principles of map-construction and map-reading have been written with a view to emphasizing the importance of this aspect of map-work as a necessary adjunct to any school geography course. As a basis of geographical teaching it should have a definite educational value both in itself and in its further application to political and economic questions. From the purely practical standpoint it is hoped that it will be of considerable value to the ordinary map-user.

As many worked examples as possible have been embodied in the text.

J. W. C.

ABERDEEN
August 1932

CONTENTS

MAPS AND MAP-WORK

CHAPTER I

INTRODUCTORY

MANY of the problems connected with maps and map-construction are directly due to the unique shape of the earth. It is like a ball flattened at its opposite poles, a solid known as a spheroid. For map-reading purposes it is near enough the truth to consider the earth as a true sphere or ball.

Now imagine an observer in an aeroplane looking down on the earth. He sees a portion of its surface, which is what a map represents on a flat piece of paper.

The problem of the representation of any portion of the earth's surface on a plane surface—that is, on paper—belongs properly to the subject of map-construction, which is not an easy one. The fact that the surface of the earth is curved makes it impossible to represent with perfect accuracy any but the minutest portion of its surface, for the surface of a sphere, unlike the curved surfaces of a cone or a cylinder, cannot be spread out flat, or 'developed.' There is a certain 'distortion' to be allowed for, the magnitude of which depends on the extent of the surface being considered. It will be useful to remember that the curved surface of the cone develops into a fan-shaped figure—a sector of a circle—and that of the cylinder into a rectangle.

In the construction of maps methods are adopted

to eliminate, or at least to counteract as far as possible, the 'distortion' error. Several of the commoner methods will be considered in a separate chapter.

In order to read a map proficiently one must be able to form a true mental picture of the ground represented, and, conversely, to visualize the map from a study of the actual ground—a much more difficult accomplishment. The knowledge of certain preliminary details is necessary. A map is a plan, and as such has to be drawn to a known scale so that distances can be measured. Representation of height is made on the map by *contours* (lines through points at the same altitude), *hachures* (shading by short lines), *spot-heights* and *bench-marks* (figured heights), and *layer-colouring* (different shades of one or more colours). Ordnance Survey maps, which are the official maps of Great Britain, are available for the whole country on a wide range of scales. These scales range from the $\frac{1}{1{,}000{,}000}$, or 15·782 miles to 1 inch, to the large scale $\frac{1}{500}$, or 126·72 inches to 1 mile. Each has its own particular use. School maps, for instance, are usually on a very small scale, and would be of little use for, say, geological or survey work, as the scale allows little more than the outline to be shown.

Maps of the Ordnance Survey

(1) $\frac{1}{1{,}000{,}000}$, *or* 15·782 *miles to* 1 *inch*. This is a map covering the whole of the United Kingdom in two sheets. The first shows Scotland, including the Orkney

and Shetland Islands, and the North of England as far south as Alnwick. The second covers Ireland and the remainder of Great Britain. Hills are shaded in brown, and coastal waters are coloured blue. The two sheets mounted together form an excellent wall map, useful for reference, as it contains a large number of place-names, but not suitable for class-work, as it lacks boldness of outline.

On the same scale a map of England and Wales, with South-west Scotland, the Channel Islands, and parts of the coasts of Ireland and France, is published, showing physical features only. It is contoured and colour-layered in green and brown for land and in blue for water features. Sea-bed contours and the corresponding bathymetric colouring add to the value of this map.

There is also a physical map of England and Wales showing approximate lines of equal magnetic variation, the magnetic values of given stations having been determined and adjusted for 1928.

Another map on the same scale, valuable for the schoolroom, is that of Roman Britain. The relief is shown on the layer system, supplemented by additional colours to indicate land between 50 and 100 feet. Roman roads, towns, villages, potteries, mines, villas and other large houses, milestones, inhabited caves, and various classes of military sites are shown. The map may be had either flat or folded in covers, the folded edition containing an explanatory account of its contents, with a list of books on the Roman occupation, a table of important events between 55 B.C. and A.D. 407, and an index of the names on the sheet.

Lastly, a map of seventeenth-century England has

been published on the same scale and based, like that of Roman Britain, on the physical map.

(2) $\frac{1}{633{,}600}$, *or* 10 *miles to* 1 *inch.* There are two editions of the map, both with water in blue:

(*a*) With contours and layer-colouring, roads in red, and names in black.
(*b*) Without contours, but with names.

The whole of Great Britain is covered in three sheets. Ireland is published in a single sheet. These small-scale maps are suitable as reference rather than as atlas maps.

(3) $\frac{1}{253{,}440}$, *or* 4 *miles to* 1 *inch.* Frequently spoken of as the 'quarter-inch' map, this covers the whole of Great Britain. There are two editions for each country:

(*a*) In outline, water in blue, but without contours.
(*b*) Contoured and layer-coloured, with water in blue.

Both are published in sheets, which are numbered in separate series for each of the three countries. Special county and district maps have been prepared by combining parts of two or more sheets of the general map.

The 'quarter-inch' map has long been the standard motoring map of the country. Roads, which are constantly being revised and brought up to date, are classified according to their character. Main roads fit for fast motor traffic are printed in red in both editions, and the Ministry of Transport road numbers are now added. England and Wales are covered in eleven

sheets and Scotland in ten. One sheet is common to both series.

(4) $\frac{1}{126,720}$, *or* 2 *miles to* 1 *inch*. This map is issued for England, Wales, and Scotland. It is printed in two forms:

(*a*) Coloured, with hills shaded—a form which is being superseded by

(*b*) layer-coloured.

For England and Wales there are forty sheets and for Scotland thirty-four. In addition to the ordinary sheet maps, special sheets of certain areas are also published.

(5) $\frac{1}{63,360}$, *or* 1 *inch to* 1 *mile*. Commonly known as the '1-inch' map, this is one of the most useful publications, and is issued in five forms for England, Wales, and Scotland:

(*a*) Outline map, with contours in orange and water in blue.

(*b*) Outline entirely in black, hills shaded in brown.

(*c*) "Popular," with contours in brown, water in blue, roads in red and brown, and woods in green.

(*d*) "Fully Coloured," with contours in red, roads in brown, water in blue, and woods in green.

(*e*) "Relief," a new series of sheets begun in 1931. Contours in brown, layer-colour changing every 500 feet, and two sets of hachures, buff and purple, giving the effect of vertical and oblique hill-shading. Water is shown in blue, roads in red and yellow, and woods in green.

The "Popular" edition of this series is very well suited for walking or cycling tours. First-class roads are shown in red, second-class roads in brown, and minor roads uncoloured. By-roads, footpaths, streams, woods, villages, etc., are all accurately shown. Contours (at 50-feet intervals) are in brown, while woods are in green. Objects of antiquarian interest are indicated by Old English or Roman characters. Parish and county boundaries are shown. Special maps of noted tourist districts are also published on this scale. On these tourist maps there is also layer-colouring.

The "Fully Coloured" edition is being gradually withdrawn, and the "Popular" edition will in time be superseded by the new "Relief" edition.

(6) $\frac{1}{10,560}$, *or* 6 *inches to* 1 *mile*. The whole of Great Britain is published on the '6-inch' scale, the series comprising over 15,000 separate sheets. Every building, road, footpath, enclosure, and waterway is clearly shown. Woods, rough pastures, rocks, and cliffs are indicated by conventional signs, houses and other buildings are ruled, while churches, schools, and public buildings are printed in black. Street names are plainly printed, latitude and longitude are noted in the margins, and all boundaries are indicated. Features of antiquarian interest are indicated by characteristic lettering. Bench-marks are given, and numerous spot-heights are shown. Contours printed in red are generally drawn at 50 feet, 100 feet, and thence at intervals of 100 feet up to 1000 feet above sea-level, and above this at intervals of 250 feet. Certain sheets are more closely contoured at intervals of 10 and 25 feet. This '6-inch' map is very useful for geological field work.

(7) $\frac{1}{2500}$, *or* 25·344 *inches to* 1 *mile.* Plans on the '25-inch' scale, as it is usually called, are published for the whole of the cultivated districts of Great Britain. Each plan measures 38 inches by $25\frac{1}{3}$ inches, and contains an area of $1\frac{1}{2}$ square miles, or 960 acres. All buildings and detail are drawn to scale, and the area of each enclosure is given in acres. Field boundaries are distinctly shown. Numerous spot-heights are shown, but the plans are not contoured. They are most useful to landowners, farmers, surveyors, and engineers. They are also of use for geological purposes.

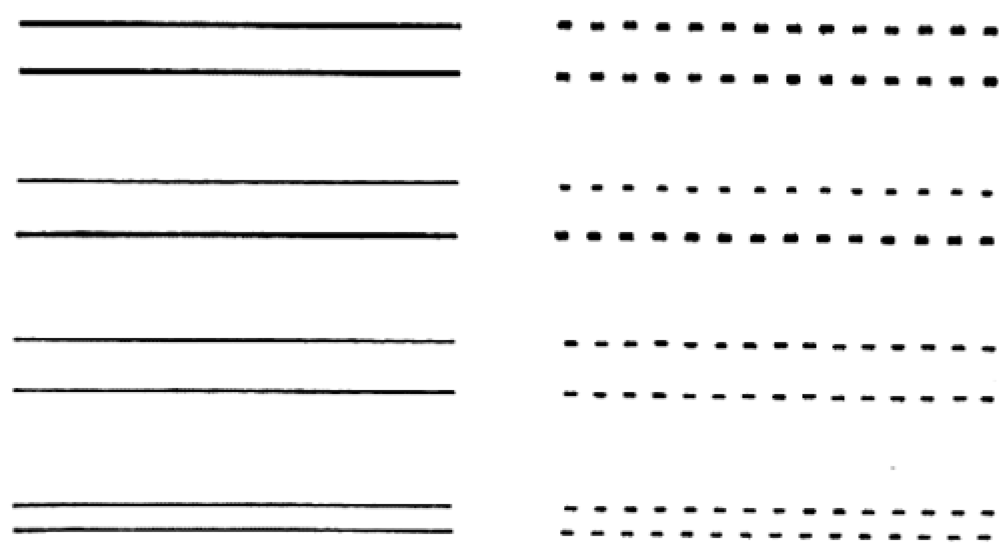
N.B. Plans on the larger scales of $\frac{1}{1056}$, or 60 inches to 1 mile, $\frac{1}{528}$, or 120 inches to 1 mile, and $\frac{1}{500}$, or 126·72 inches to 1 mile, are now out of use, and are only produced nowadays at the request of municipalities which undertake to pay the extra cost of the survey. If a very large scale is required a $\frac{1}{1250}$ or '50-inch' (accurately '50·688-inch') enlargement from the $\frac{1}{2500}$ scale can always be obtained, and is sufficient for almost every practical purpose.

Full descriptions, with specimens, of Ordnance Survey maps can be found in two pamphlets on large-scale and small-scale maps respectively, published by the Ordnance Survey.

The various methods of showing heights and the nature of their slopes on the map will be considered in a separate chapter. It is necessary also to make use of various symbols known as conventional signs to

indicate certain features. The following are worthy of note:

ROADS	*Fenced*	*Unfenced*
1st Class		
2nd Class		
3rd Class		
4th Class (unmetalled)		



As already noted, colours are also used for roads on many maps.

A footpath is indicated thus:

This peck-line must be distinguished from a dotted line, which shows the boundary of a parish.

RAILWAYS

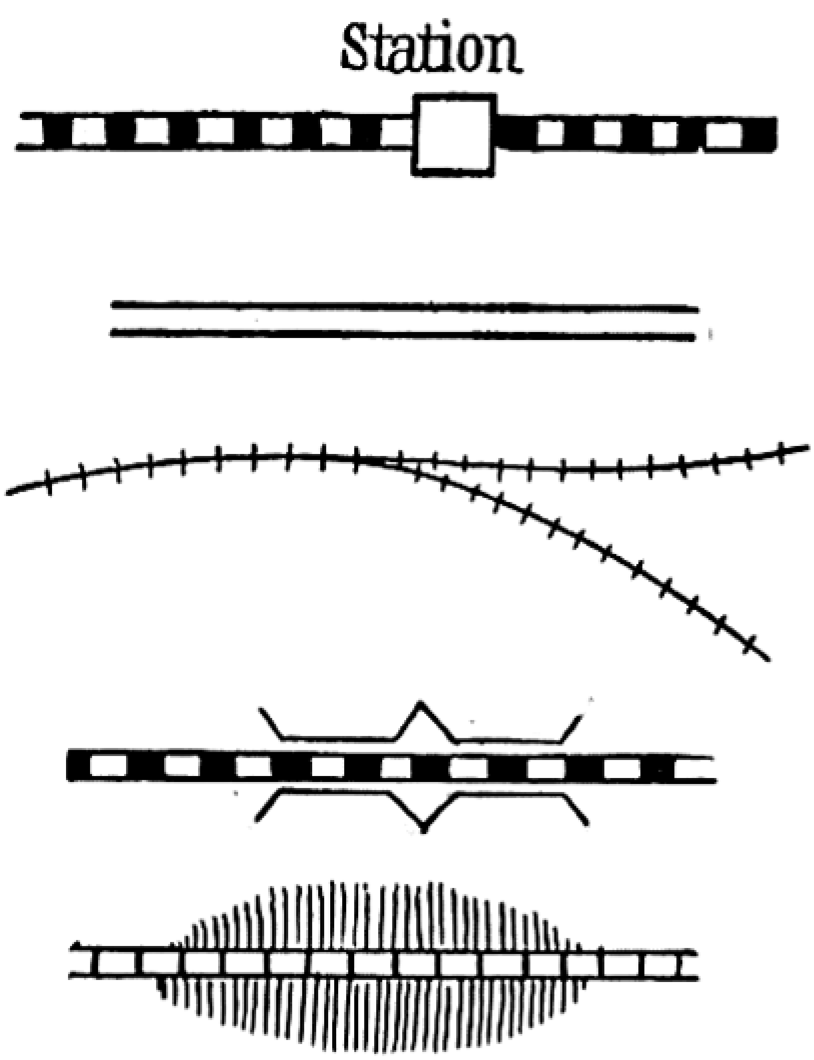
Two and more lines

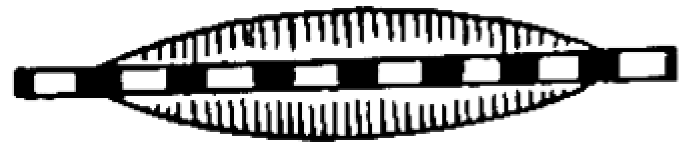
Single lines

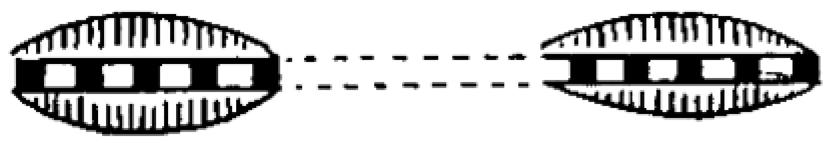
Mineral lines and tramways

Viaduct

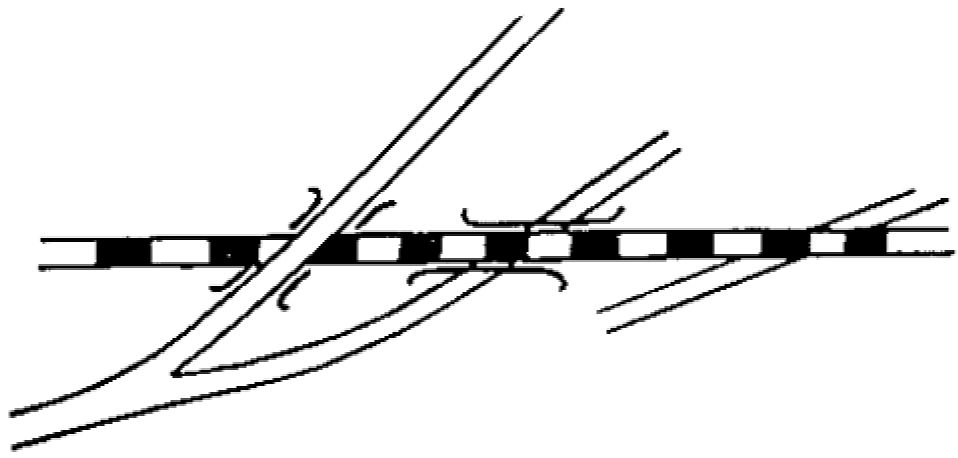
Embankment



Cutting 

Tunnel 

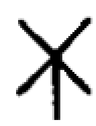
Road over railway
„ under „
Bridges shown by conventional signs
Level crossing

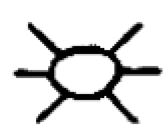


MISCELLANEOUS

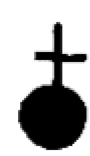
Canal and locks 

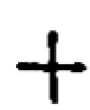
Aqueduct 

Wind-pump 

Windmill 

Church or chapel with tower 

„ „ „ „ spire 

„ „ „ without either 

Village post office P.

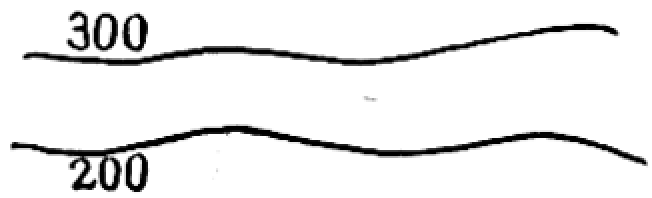
„ „ and telegraph office T.

Letter-box L.B.

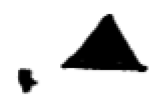
Milestone 5

Heights in feet 135

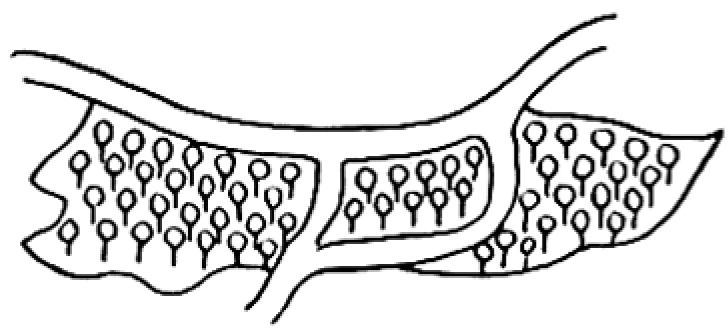
Contours in feet

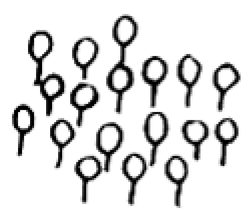


Trigonometrical point

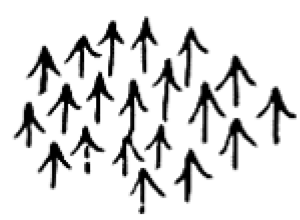


Orchards

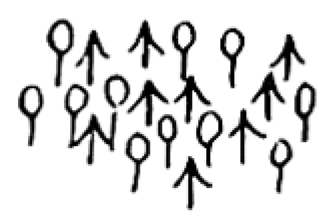




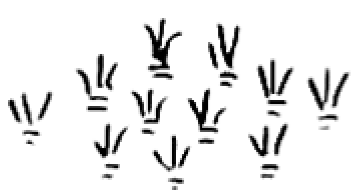
Woods: deciduous trees



Woods: coniferous trees



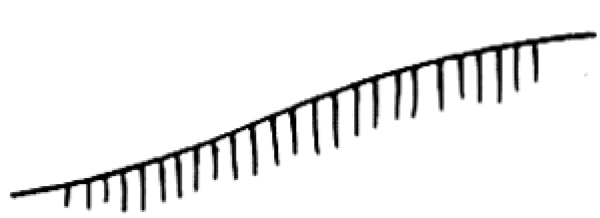
Woods: mixed trees



Marsh

Gravel pit

Quarry



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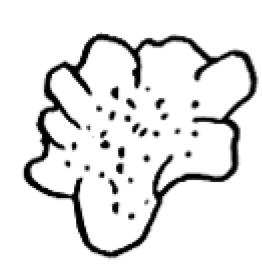
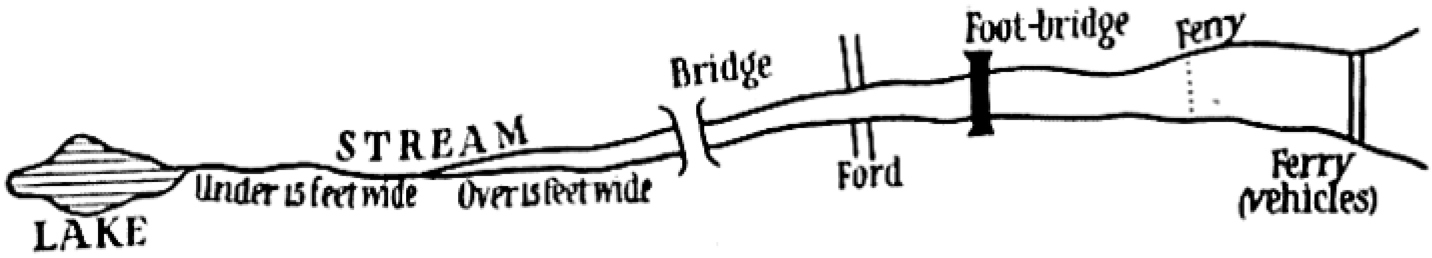




CHAPTER II

SCALES AND THEIR CONSTRUCTION

IT is essential to the accuracy of a map or a chart that any distance measured on it should bear to any other measured distance the same ratio as their actual measurements on the ground. In short, everything must be drawn 'to scale.' A scale is therefore the relation which any length on a map bears to its corresponding distance on the ground. A scale may be expressed in one or more of the following ways:

1. By a statement—*e.g.*, 1 inch to 1 mile, or 2 miles to 1 inch.

2. By a line divided into a number of equal parts, each representing a number of miles, yards, feet, or other units. One of the units may be subdivided into smaller units. This is a graphic, or plain, scale.

Example:

3. By a representative fraction, or R.F.

This method expresses the relation between map and ground as a fraction, with numerator 1 and denominator any number of similar units.

$$\text{R.F.} = \frac{\text{map distance}}{\text{ground distance}}.$$

For the well-known '1-inch' Ordnance Survey map

$$\text{R.F.} = \frac{1 \text{ inch}}{1 \text{ mile}} = \frac{1}{63{,}360}.$$

This means that 1 inch on the map represents 63,360 inches, or 1 mile, on the ground. It is equally true that one unit of measurement—inch, foot, yard, centimetre, etc.—on the map represents 63,360 similar units on the ground. The chief purpose of an R.F. is to enable a scale to be constructed—if necessary—which is in a different unit from that of the given map scale. For example, a scale of yards might be made on a map on which the graphic scale was in centimetres.

If the R.F. is given the scale may be expressed as inches to 1 mile or miles to 1 inch, according to the relation which the denominator bears to 63,360.

(*a*) $\frac{1}{10{,}560}$ (denominator less than 63,360).

Here 10,560 inches on the ground are represented by 1 inch on the map.

I.e., 1 inch on the ground is represented by $\frac{1}{10{,}560}$ inch on the map.

$\therefore$ 63,360 inches on the ground are represented by $\frac{63{,}360}{10{,}560}$ (= 6) inches on the map. Large scale

$\therefore$ scale is 6 inches to 1 mile.

(*b*) $\frac{1}{633{,}600}$ (denominator greater than 63,360).

Here 633,600 inches on the ground are represented by 1 inch on the map.

I.e., $\frac{633{,}600}{63{,}360}$ (= 10) miles on the ground are represented by 1 inch on the map. Small scale

$\therefore$ scale is 10 miles to 1 inch.

Thus, if the denominator of the R.F. is less than 63,360 divide 63,360 by it, and the result gives inches

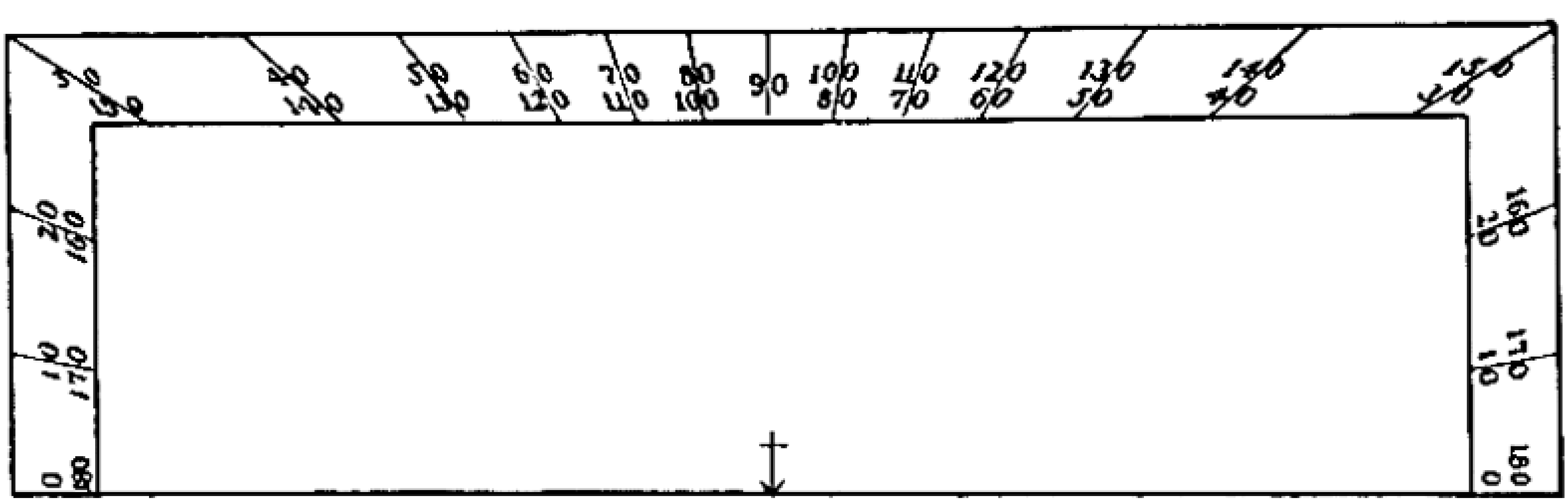
to 1 mile. If the denominator is greater than 63,360 divide it by 63,360, and the result gives miles to 1 inch.

When the denominator is 63,360 the scale is exactly 1 inch to 1 mile.

It is frequently desirable to construct a graphic scale when the map does not contain one. The beginner usually finds difficulty in deciding the length to make a scale. In most cases a line about 6 inches long is found sufficient.

Two instruments for measuring angles and distances respectively might be mentioned here. These are the *protractor* and the *diagonal scale.*

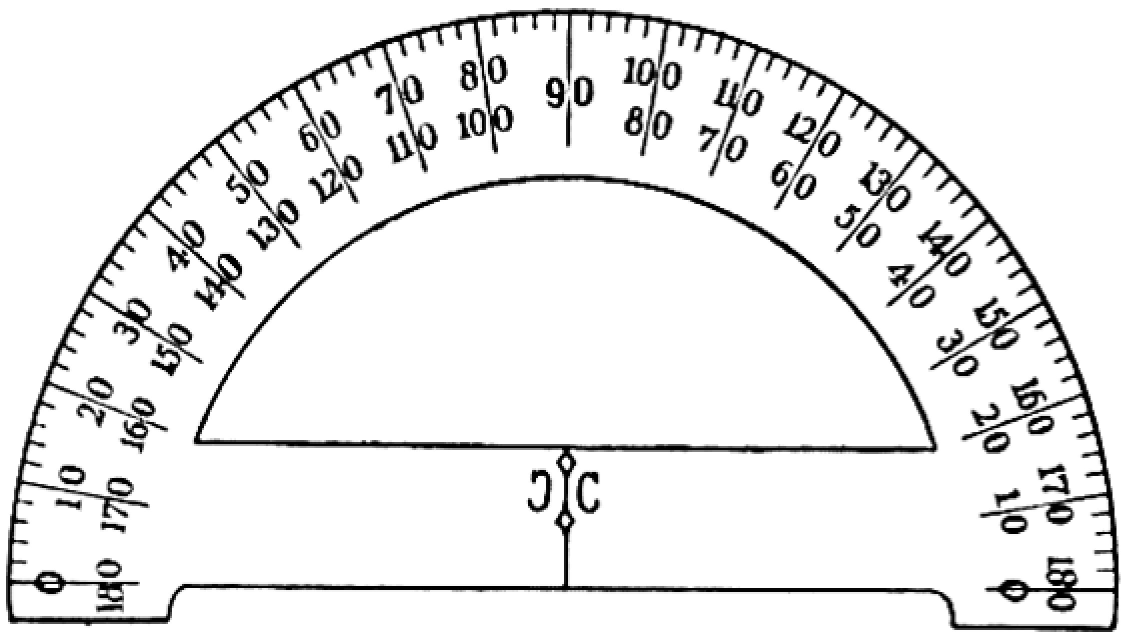
Protractor. This is a very simple but useful instrument for making and measuring angles. There are two



varieties in ordinary use: the rectangular boxwood and the semicircular celluloid. The former is an ordinary school instrument, good enough for most purposes. A better one is the 6 inch × 2 inch rectangular service protractor, which, in addition to being graduated in degrees round the edge, shows various scales of yards and miles and also one scale of kilometres $\left(\frac{1}{100,000}\right)$.

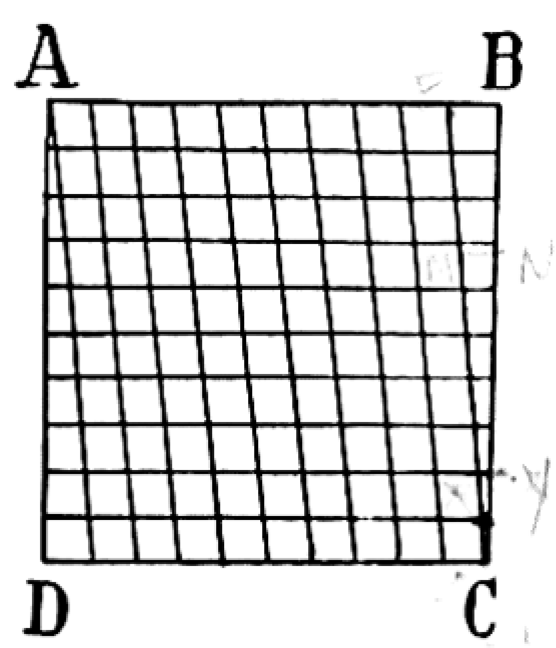
The semicircular celluloid protractor often shows several scales of yards in addition to its graduation in

degrees. Angles up to 360° can be measured or constructed, as it contains an outer set of graduations reading from 0° to 180° and an inner set from 0° to



180°, the inner set of figures being supplementary to the outer (the sum of supplementary angles is 180°).

Diagonal Scales. Sometimes measurements to a hundredth part of an inch, which an ordinary ruler is not graduated to show, are necessary in the construction of scales. Such measurements can be got from a diagonal scale.



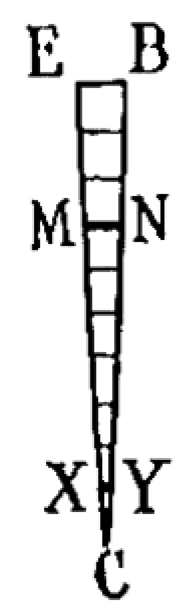
ABCD is a square of 1-inch side. AB, AD, and DC are each divided into ten equal parts, each part being therefore $\frac{1}{10}$ inch long. Through the divisions on AD lines are drawn parallel to AB. The marks on AB and

DC are then joined diagonally, each mark on the bottom margin being joined to the mark on the top margin $\frac{1}{10}$ inch farther to the left.

Let EB, MN, and XY be lengths on the diagonal scale ABCD.

Considering the triangle EBC, we have, by geometry,

$$\frac{XY}{EB} = \frac{CY}{CB} = \frac{1}{10}.$$



$$\therefore XY = \frac{1}{10} EB$$

$$= \frac{1}{10} \text{ of } \frac{1}{10} \text{ inch}$$

$$= \frac{1}{100} \text{ inch, or } \cdot 01 \text{ inch.}$$

Similarly, $\quad MN = \frac{7}{100}$ inch, or ·07 inch.

In the same way a diagonal scale might be made to show yards, feet, and inches. AB in this case would be divided into three equal parts and AD into twelve.

Example 1. Construct a scale of $1\frac{1}{2}$ inches to 1 mile to show 3000 yards and hundreds of yards.

$$\text{R.F.} = \frac{1\frac{1}{2}}{63{,}360} = \frac{3}{126{,}720} = \frac{1}{42{,}240}.$$

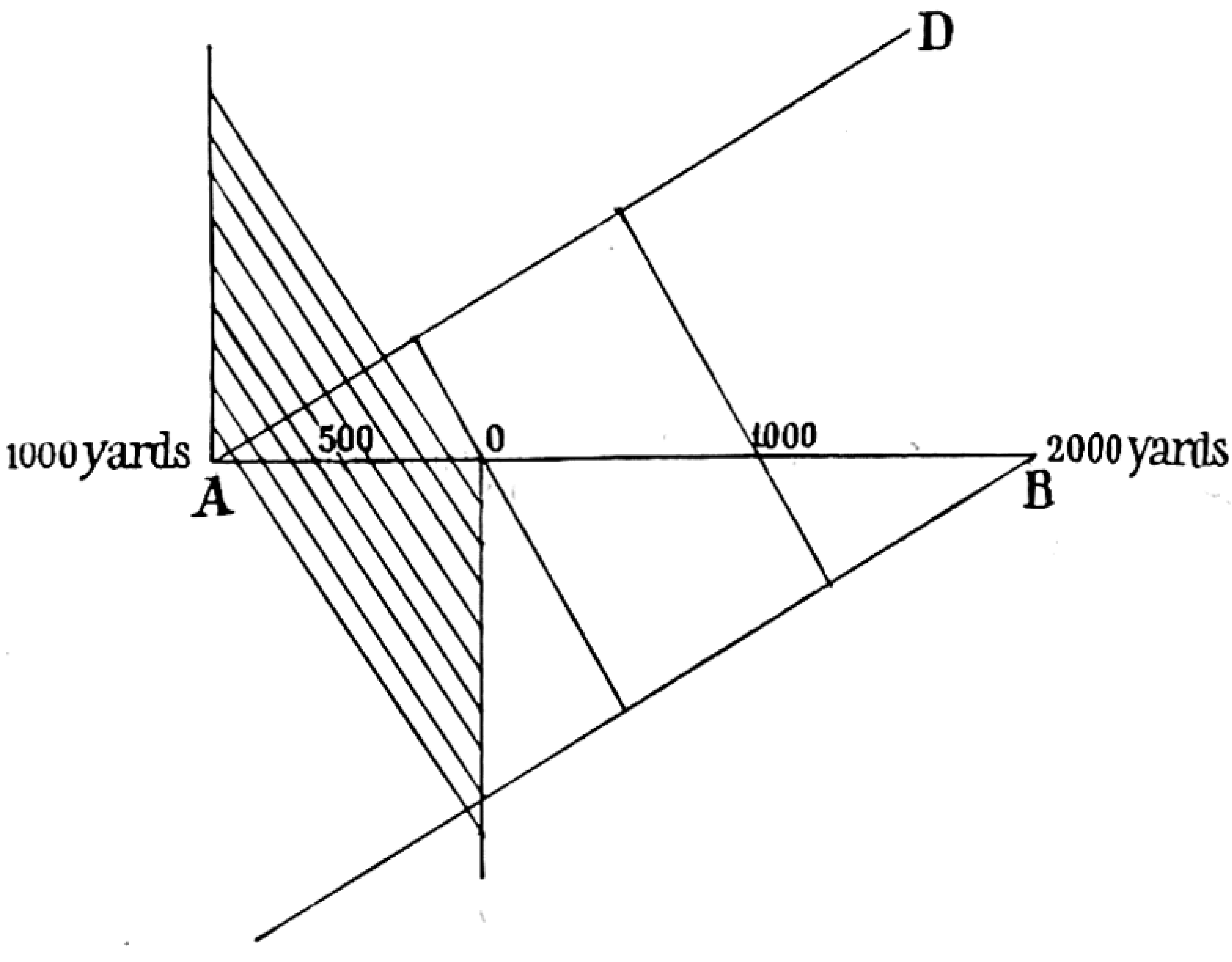
I.e., 42,240 yards are represented by 1 yard, or 36 inches.

$\therefore$ 1 yard is represented by $\frac{36}{42{,}240}$ inch.

$\therefore$ 3000 yards are represented by $\frac{36 \times 3000}{42{,}240}$ $(= 2 \cdot 55)$ inches.

A line AB, 2·55 inches in length, is then drawn. This length may be accurately measured from a diagonal scale.

At A set off a line AD at any angle with AB. From A mark off any two equal parts on this line. Then at B set off a line parallel with AD on the opposite side

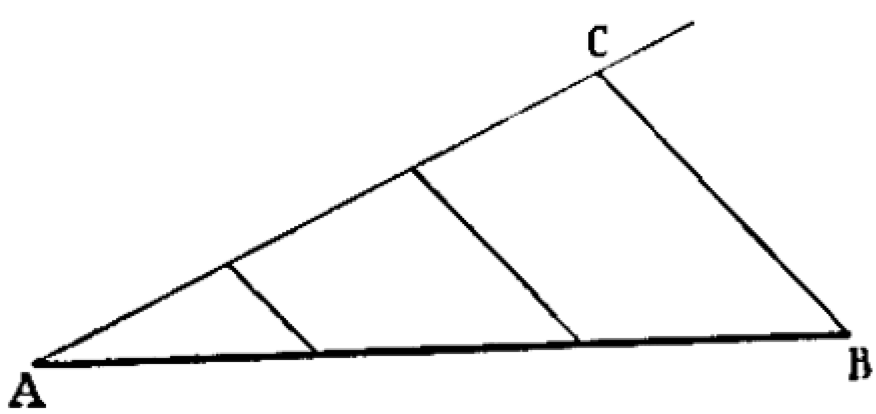


of the scale line. Along this line mark two similar parts from B. The opposite marks on the two construction lines are then joined, thus dividing the scale line into three equal parts, each of which represents 1000 yards.

The left-hand division, as the most convenient, should then be divided by a similar method into ten equal parts, each of which will represent 100 yards.

The scale is then marked as shown. Construction lines should be drawn lightly in pencil so that they may be rubbed out when the scale is completed.

Note. (*a*) A line may be divided into any number of equal parts by the use of ruler and set-squares only. From one end A of the line AB set off a line at any angle with AB. Along this line measure, from A, any number (say three) of equal parts. Let C be the other end of the portion of the line thus divided into three parts. Join CB, and through the other two points draw parallels to CB. These divide AB into three equal parts.



(*b*) Sometimes a protractor is not available for measuring angles. In this case the following two methods will give satisfactory results.

1. Take a piece of paper with a straight edge and about three inches wide. Place an end of it on one end of the given line and with the straight edge lying along it. At a convenient spot on the far edge of the paper mark a point and transfer it to the paper on which the scale is being drawn. Then reverse the paper to the other side and end of the scale line and make a mark on the scale paper to coincide with the mark on the loose paper. Two marks are thus made, by joining which to the respective ends of the scale line equal angles are obtained. The scale line may then be divided as indicated in the preceding example.

2. A piece of paper can be folded to form a convenient angle and applied to each end of the scale line in turn.

Example 1 (*alternative method*).

$1\frac{1}{2}$ inches represent 1760 yards.

$\therefore$ $\frac{3}{8}$ inch represents 440 yards.

$\therefore$ $1\frac{7}{8}$ inches represent 2200 yards.

A line $1\frac{7}{8}$ inches may therefore be drawn and divided into eleven equal parts, each of which will represent 200 yards. One of the divisions will require to be divided into two equal parts to show hundreds of yards. As the scale is for use up to 3000 yards, the requisite distance is obtained by producing the line a distance equal to four divisions of the original line.

Example 2. The R.F. of a map is $\frac{1}{30,000}$. Construct a scale to read thousands of yards and hundreds of yards.

If the length of scale to be made is 6 inches it will be necessary first to find the number of yards represented by a line 6 inches long.

In this case 30,000 yards are represented by 1 yard, or 36 inches.

$$\therefore \text{ 5000 yards are represented by } \frac{36}{6} \ (= 6) \text{ inches.}$$

A line 6 inches long is then drawn and divided into five equal parts, one of which is subdivided into ten equal parts to show hundreds of yards.

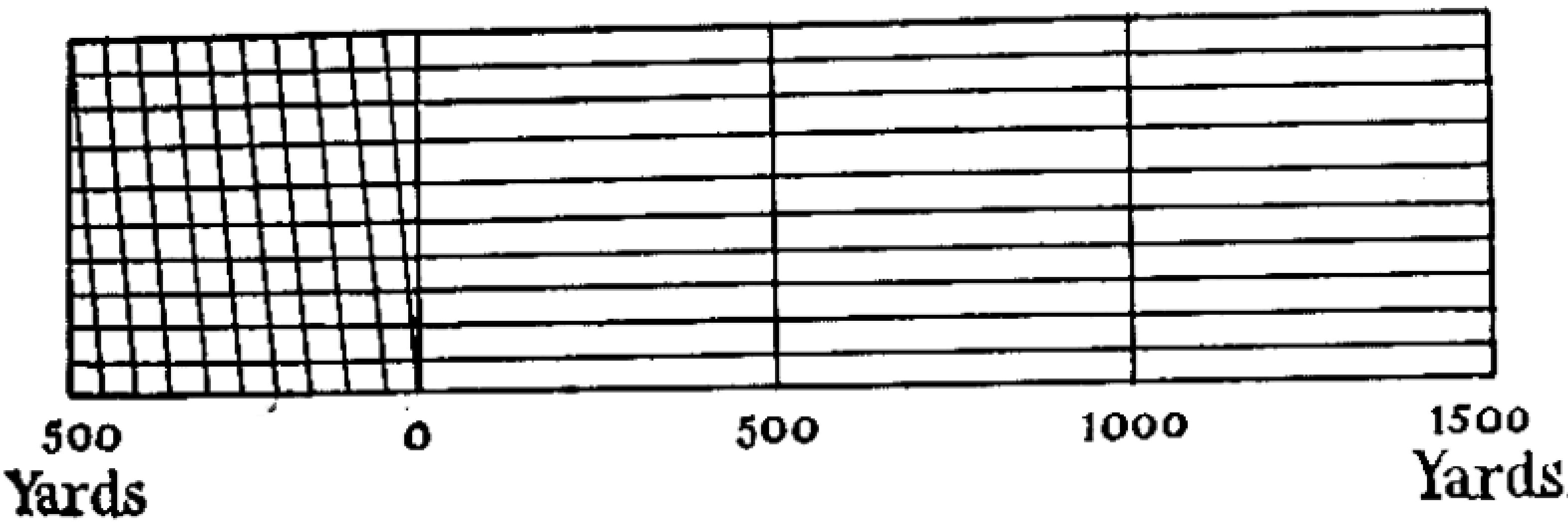
Example 3. Construct a diagonal scale for use with a $\frac{1}{20,000}$ map to read up to 2000 yards.

20,000 yards are represented by 1 yard, or 36 inches.

$$\therefore \text{ 500 yards are represented by } \frac{36}{40} \ (= \cdot 9) \text{ inch.}$$

$\therefore$ 2000 yards are represented by 3·6 inches.

The scale line can then be drawn and divided into four equal parts, each of which will represent 500 yards. One of these divisions is used to make a diagonal scale which will show 5 yards and multiples.



Measure on this scale the following lines:

1.

2.

3.

Comparative Scales. These are scales made from the same R.F. to read different units. For example, on some maps a scale reading hundreds and thousands of yards and another reading hundreds and thousands of metres are given.

Time Scales. If it is required to show the distance traversed while moving at any specified rate a time scale can be constructed.

E.g., construct a time scale for a map 1 inch to 1 mile for a scout march at 3 miles per hour.

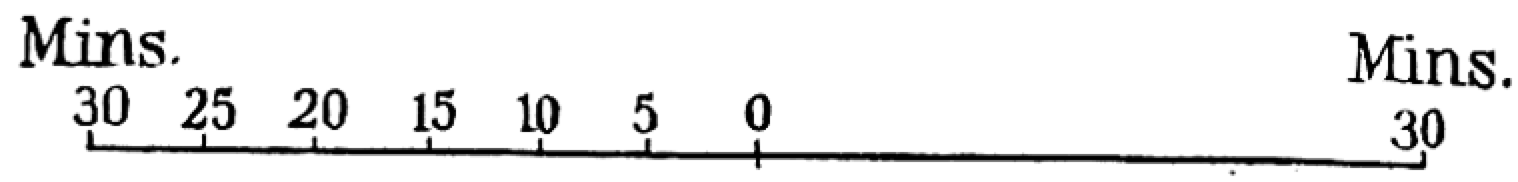
1 inch represents 1 mile.

$\therefore$ 3 inches represent 3 miles (the ground traversed in 1 hour),

and $\frac{1}{4}$ inch represents $\frac{1}{4}$ mile (the ground traversed in 5 minutes).

A line 3 inches long is drawn and bisected. The centre is numbered 0 and the right-hand end of the

line 30 minutes. The half of the line to the left of the 0 is subdivided into six equal parts, each representing



a period of 5 minutes and numbered up to 30 (right to left).

Improvised Scales. These are sometimes made if none of the usual instruments are available for the construction. The simplest way is to take a piece of paper, say 4 inches long, and fold it into any number of equal parts, each part to represent, say, 100 yards. The fewer the folds the greater will be the scale. Afterward the length of a fold can be carefully measured, an R.F. made, and the scale constructed.

EXERCISES

1. Construct a scale for a $\frac{1}{20,000}$ map to read 3000 yards and hundreds of yards.

2. Construct a scale for a 2 inches to 1 mile map to read 5000 yards and hundreds of yards.

3. Express in inches to the mile or miles to the inch:

   (*a*) $\frac{1}{63,360}$; (*b*) $\frac{1}{10,560}$; (*c*) $\frac{1}{5000}$; (*d*) $\frac{1}{100,000}$.

4. Convert into R.F.'s:

   (*a*) 1 inch to 1 mile; (*b*) 4 inches to 1 mile; (*c*) 6 inches to 1 mile; (*d*) 5 miles to 1 inch; (*e*) 2 miles to 1 inch.

5. Two places are represented 3 inches apart on the map. The R.F. of the map is $\frac{1}{20,000}$. Find the actual distance between the two places.

6. Two places are represented $2\frac{1}{4}$ inches apart on the map. Their actual distance apart is 1250 yards. Find the R.F. of the map.

7. A straight stretch of railway is shown as 3 inches long on the

map. A train travelling at 60 miles per hour covers the distance in 5 minutes. Find the R.F. of the map.

8. Construct a diagonal scale for use with

(*a*) a $\frac{1}{10,000}$ map to read up to 1500 yards;

(*b*) a $\frac{1}{25,000}$ map to read up to 5000 yards.

9. Construct a time scale for a '1-inch' map for travelling at 4 miles per hour.

10. Construct a time scale for a $\frac{1}{20,000}$ map for travelling at 3 miles per hour.

ANSWERS

1. 5·4 inches represent 3000 yards.
2. 5 inches represent 4400 yards. (Extend line necessary length to read 5000 yards.) Or 5·68 inches represent 5000 yards.
3. (*a*) 1 inch to 1 mile; (*b*) 6 inches to 1 mile; (*c*) 12·6 inches to 1 mile; (*d*) 1·5 miles to 1 inch.
4. (*a*) $\frac{1}{63,360}$; (*b*) $\frac{1}{15,840}$; (*c*) $\frac{1}{10,560}$; (*d*) $\frac{1}{316,800}$; (*e*) $\frac{1}{126,720}$.
5. 1666·6 yards.
6. $\frac{1}{20,000}$.
7. $\frac{1}{105,600}$.
8. (*a*) 1·8 inches represent 500 yards; (*b*) 7·2 inches represent 5000 yards.
9. 6 inches represent $1\frac{1}{2}$ hours. $\frac{1}{3}$ inch represents 5 minutes.
10. 9·5 inches represent 1 hour. ·8 inch represents 5 minutes.

CHAPTER III

MAP PROJECTIONS

If the earth were cylindrical or conical in shape, it would be easy to draw on a flat piece of paper a map in which every feature was shown correct in shape, in position, and in proportion to other features. It would merely be necessary to imagine the cylinder or cone unrolled till flat, or 'developed.' The methods of drawing the earth's curved surface on a plane with the least possible error are called 'projections.' They are not projections in the mathematical sense, but are 'developments' from the cylinder or the cone.

A map projection is any definite system of drawing meridians and parallels, the network of lines thus formed being called a *map-net* or *graticule*.

The thirty or more methods devised for the construction of maps all differ in value according to the use for which the map is intended. The distortion that inevitably results from representing a curved surface on a plane surface naturally involves an inaccuracy in one or more of the values of the map: the representation of scale, area, shape, and direction. For some purposes correct shape is more important than correct area: for others the reverse is true. Since the map can never be a true representation of the earth's surface the scale can never be true over the whole map. These considerations have only theoretical value in the case of large-scale maps of small areas, for which the inaccuracies are so minute as to be inappreciable for practical purposes.

Three classes of projections may be distinguished:

1. Zenithal or azimuthal.
2. Conical.
3. Cylindrical.

1. **Zenithal Projections.** These projections depend on the fact that a plane touches a sphere in a point. The planes of the great circles, or meridians, passing through the poles cut such a tangent plane in straight lines. Thus, if the plane touches the globe at one of the poles, the meridians will appear as straight lines radiating outward from the point which is to represent the pole. The parallels of latitude will be concentric circles round this point, which is their common centre.

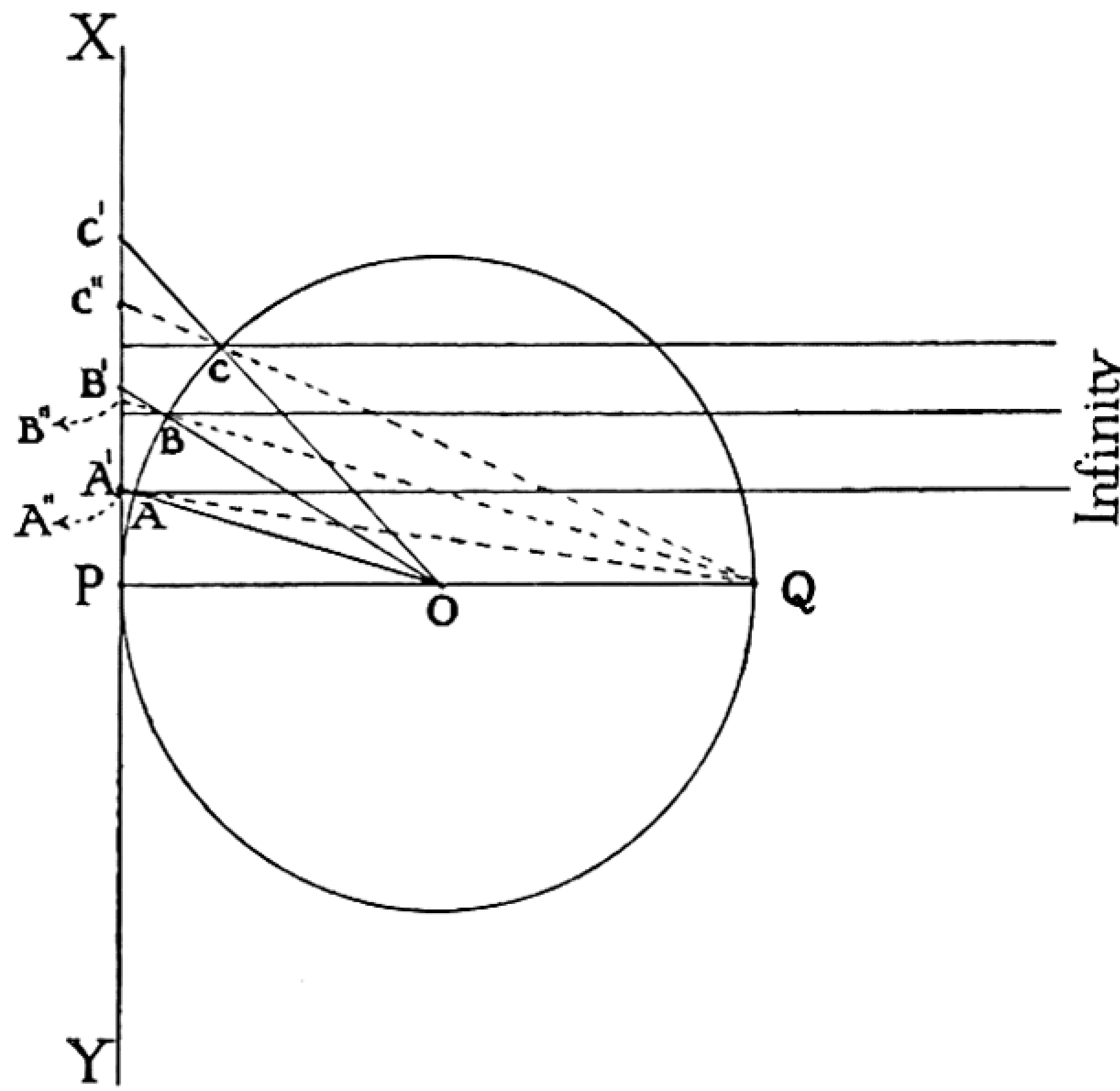
Zenithal projections may thus be considered as constructed upon a plane touching the sphere. This tangent plane does not usually touch the sphere at the pole—which is the normal case—but obliquely to the axis of the sphere at any agreed-on point, which then becomes the centre of the map.

Zenithal projections keep the true bearings of all points from the vertex, or centre, of the map, and are useful for representing the polar regions in atlas maps. They are also called azimuthal projections, since the direction, or azimuth, of any point from the centre of the map is shown by a straight line.

There is a group of zenithal projections, known as perspective projections, which are true geometrical projections made by projecting a portion of the sphere upon a plane by straight rays proceeding from a centre, or focus, of projection.

Let the circle represent a meridian of the earth with PQ as diameter. XY, at right angles to PQ, is a section

of a plane touching the sphere at P. The centre of projection, at which the eye is imagined to be placed, is taken at some point in PQ or PQ produced. Then the position of any place on the map is the point where the line of sight through the place on the sphere cuts the tangent plane.



(*a*) If the centre of projection be O, places A, B, and C will be represented on the tangent plane by A′, B′, and C′, giving what is known as the *gnomonic*, or *central*, projection. Although distances, areas, and shapes are badly represented, the gnomonic projection has the useful property of causing any great circle on the sphere to appear on the map as a straight line. It differs from Mercator's projection in having the parallels of latitude curved.

(*b*) If the centre of projection be Q, places A, B, and C will be represented by A″, B″, and C″. The projec-

tion is then known as the *stereographic*, and this is probably the most useful of the perspective zenithal projections. In this map every circle on the earth, great or small, is represented by a circle, and all angles are reproduced correctly, so that, in consequence, outlines over the globe are correctly delineated on the map. This projection was frequently used in the past for atlas maps of continents, but is little used now. It is easy to draw the stereographic projection of a hemisphere upon a small scale. If, however, a large-scale map of a small portion of the earth be required it is difficult in practice to draw the meridians and parallels, as too large a sheet would be required.

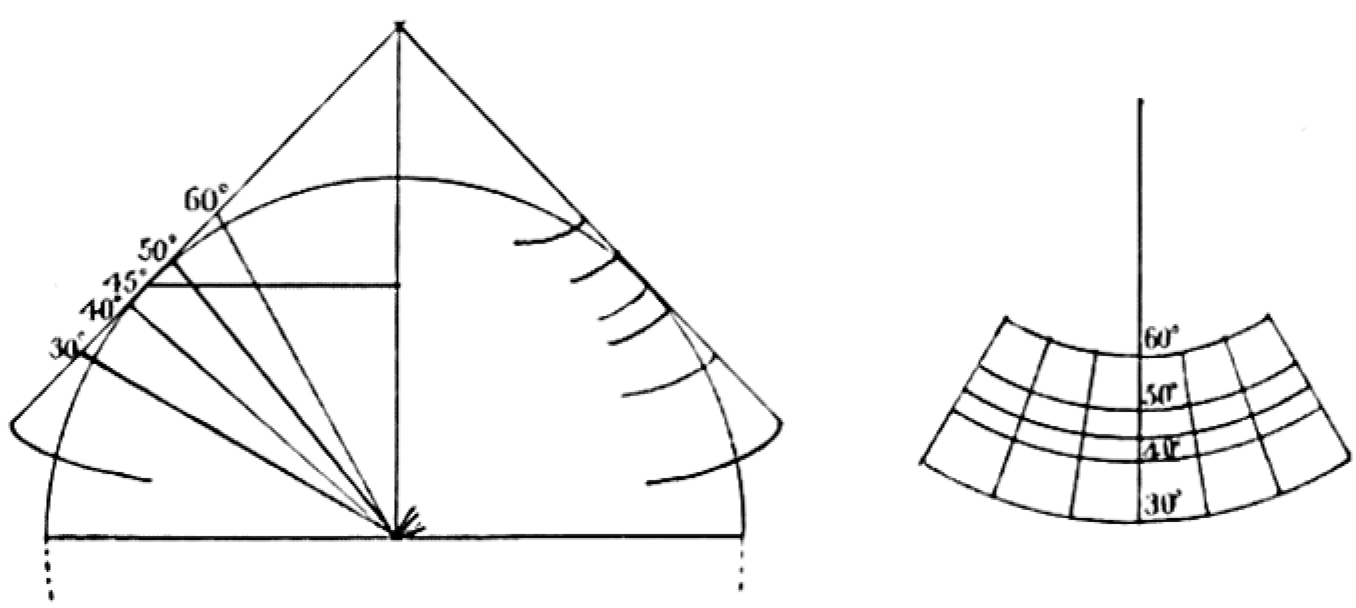
If the centre of projection be taken in OQ produced at a distance from the centre of the sphere between 1·35 and 1·65 times the radius, at which distance the distortion is kept within the strictest limits, the perspective projection known as *Clarke's minimum error* projection is produced. It is most suitable for the representation of a hemisphere or larger portion of the sphere.

When the distance of the centre of projection from the centre of the sphere is about 1·37 times the radius the projection is known as *Sir Henry James's* projection.

(*c*) If the centre of projection be transferred to an infinite distance the rays of projection become parallel straight lines, striking the tangent plane at right angles, and the projection is known as the *orthographic*, or *picture*, projection. Such a projection is not of much use for geographical purposes, but is utilized by astronomers in depicting the heavenly bodies, which are practically at an infinitely remote distance.

2. **Conical Projections.** These are among the most important of all. Imagine the globe enclosed in a

conical cap of paper which fits against it at the parallel of latitude 45°. The projection is then made on this cone. It is clear that the cone touches the globe along the parallel which is of true length. This means that if the scale of the map is, say, $\frac{1}{20,000,000}$, the length of the complete parallel on the map is $\frac{1}{20,000,000}$ the length of the corresponding parallel on the globe. Along this parallel of contact, or standard parallel, the



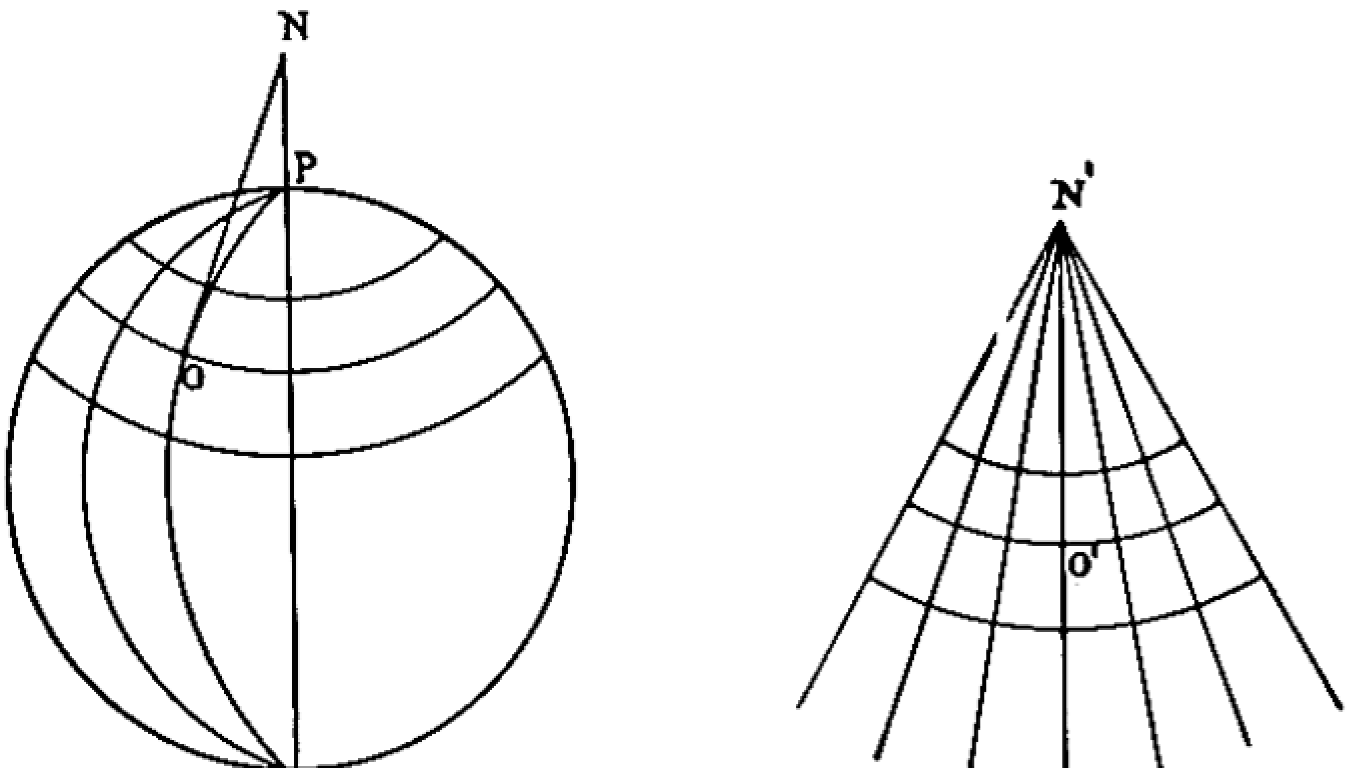
representation is correct. In fact, within a short distance on either side of it the surface of the cone is almost the same as the surface of the earth near the same parallel.

In the typical conical projection the meridians are straight lines which if produced would meet in one point, while the parallels are arcs of concentric circles, the common centre of which is the point of intersection of the meridians.

Note. When the cone is developed the standard parallel becomes an arc of a circle, the radius of which is greater than the radius of the circle of contact. The meridians are then parts of the radii of the concentric circles.

One of the most useful modifications of the conical projection, which makes it possible to obtain fairly accurate maps for wider limits, is the *simple conical* map which may be constructed with one or two parallels of true length. The simple conical projection with one standard parallel which is suggested by the tangent cone is constructed thus:

Let OP represent, to scale, the meridian passing through O, some point in the area to be mapped. P



represents the geographical pole of the earth. OP will thus represent the central meridian and the parallel through O the standard parallel. Let the tangent to the central meridian at O cut the axis of the earth at N. Then the cone which touches the sphere at the parallel of O is the cone to be developed, and the radius of the standard parallel on this developed cone is ON. A vertical line O′N′ is drawn to represent the central meridian, O′N′ being made equal to ON. With centre N′ and radius N′O′ an arc is drawn to represent the parallel through O. Along the arc and on either side of O′N′ distances are set off corresponding to 10° or 15° of longitude and the points joined to N′.

For the remaining parallels lengths must be set off along one of the meridians and through the points of division circles concentric with the standard parallel drawn.

In this projection the scale is true only along the standard parallel and along the meridians. On both sides of the standard parallel the scale is too great, and consequently areas are too large. It can be seen that the North Pole is represented by an arc of a circle. The South Pole would appear much larger than the equator. The projection is therefore not suitable for high latitudes; so that the smaller the range in latitude the better will be the map. It is not suitable for world maps, but it is largely used for atlas maps of single countries of moderate latitude. Countries having a wide range of longitude, such as British North America, lend themselves to this projection, while some of the Ordnance Survey maps of Scotland are drawn on a modification of it.

The error of scale in the simple conical projection can be lessened by making two standard parallels instead of one. With two standard parallels of true length and at the correct distance apart it is necessary to select the standard parallels to suit the extent of the area to be mapped. Suppose, for example, a map is to be constructed of Europe, which lies roughly between parallels 35° north and 70° north, an extent of latitude of 35°. It has been found sufficient to take the standard parallels at a seventh of this extent of latitude from the bounding parallels. In this case, $\frac{1}{7}$ of 35° being 5°, the standard parallels will be at 40° and 65°. For Europe the extent of longitude is 10° west to 30° east;

so that if the central meridian be taken as 10° east there will be an extent of 20° longitude on each side of it. The length of 1° for parallels 40° and 65° can be got from tables. At latitude 40° the length of 1° is 53·06 miles, while at 65° it is 29·31 miles. As there are to be 20° on either side of the central meridian, the length of 1° on the respective parallels will be multiplied by 20 and the distance reduced to the scale on which the map is to be constructed. For example, on a scale of $\frac{1}{20{,}000{,}000}$ it will be found that the parallels will extend 3·36 inches (approximately) and 1·86 inches (approximately) on either side of the central meridian.

It can also be found by calculation that the distance between the standard parallels, which are to be at their true distance apart, will be represented on the map by 5·5 inches.

A vertical line XY is drawn 5·5 inches long. YM and XN, 3·36 inches and 1·86 inches respectively, are drawn at right angles to it. MN is joined and produced to meet YX produced in O, which is the centre of the concentric circles representing parallels. The meridians are straight lines drawn through O, OM being the meridian of 10° west. With centre O and radii OX and OY arcs are drawn to represent the standard parallels.

The map-net can then be completed and the outline sketched in from an atlas map by making use of the intersection of meridians and parallels. It is easy to find the length of the radii (OX and OY) of the standard parallels by calculation.

Draw NP at right angles to MY.

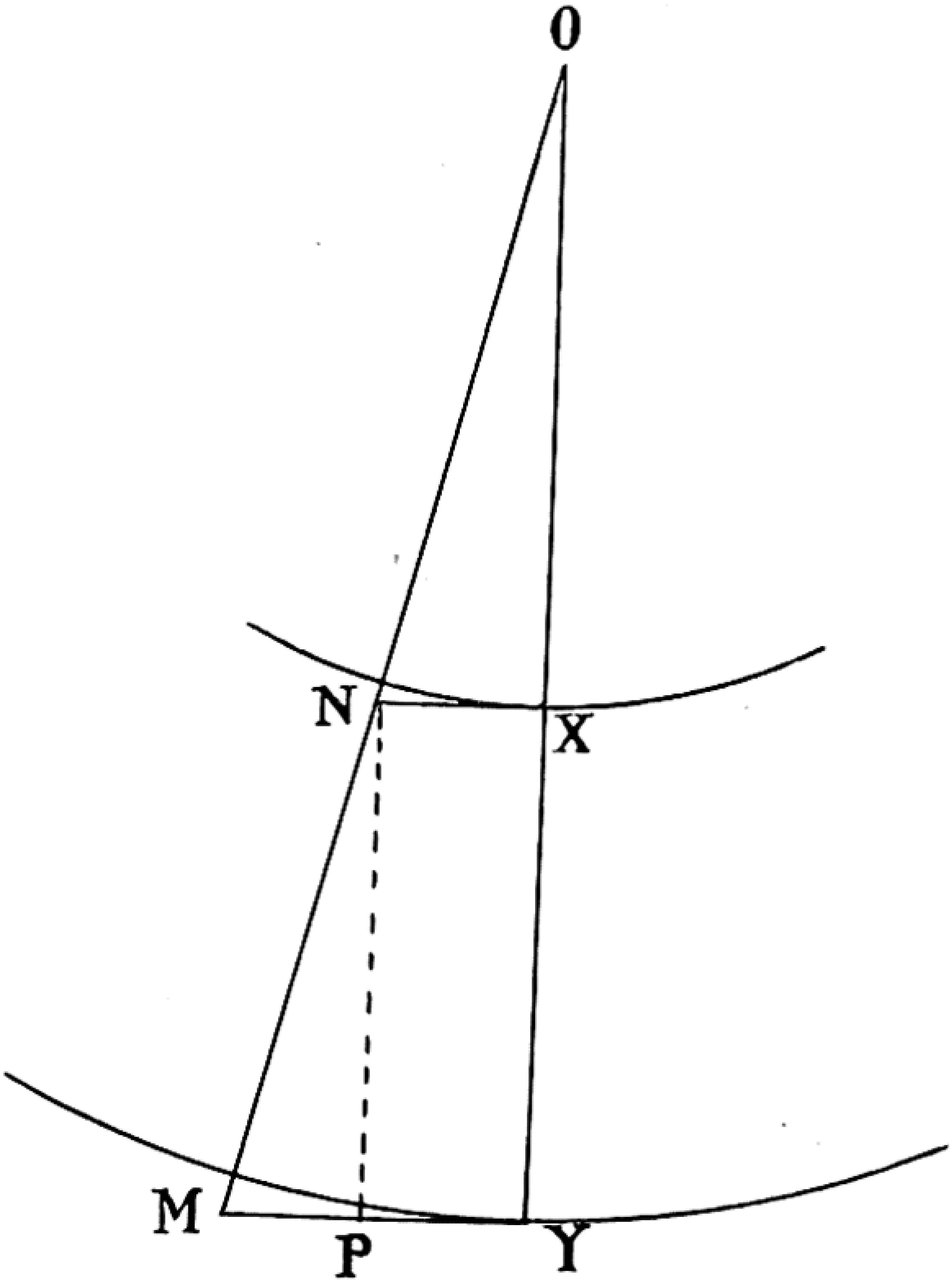
From the diagram (by similar triangles)

$$\frac{OX}{XN} = \frac{NP}{PM}.$$

$$\therefore OX = XN \times \frac{NP}{PM}$$

$$= 1{\cdot}86 \text{ inches} \times \frac{5{\cdot}5}{1{\cdot}5}$$

$$= 6{\cdot}82 \text{ inches.}$$



The length of OX can be checked on the diagram.

And $$OY = OX + XY$$

$$= 6{\cdot}82 \text{ inches} + 5{\cdot}5 \text{ inches}$$

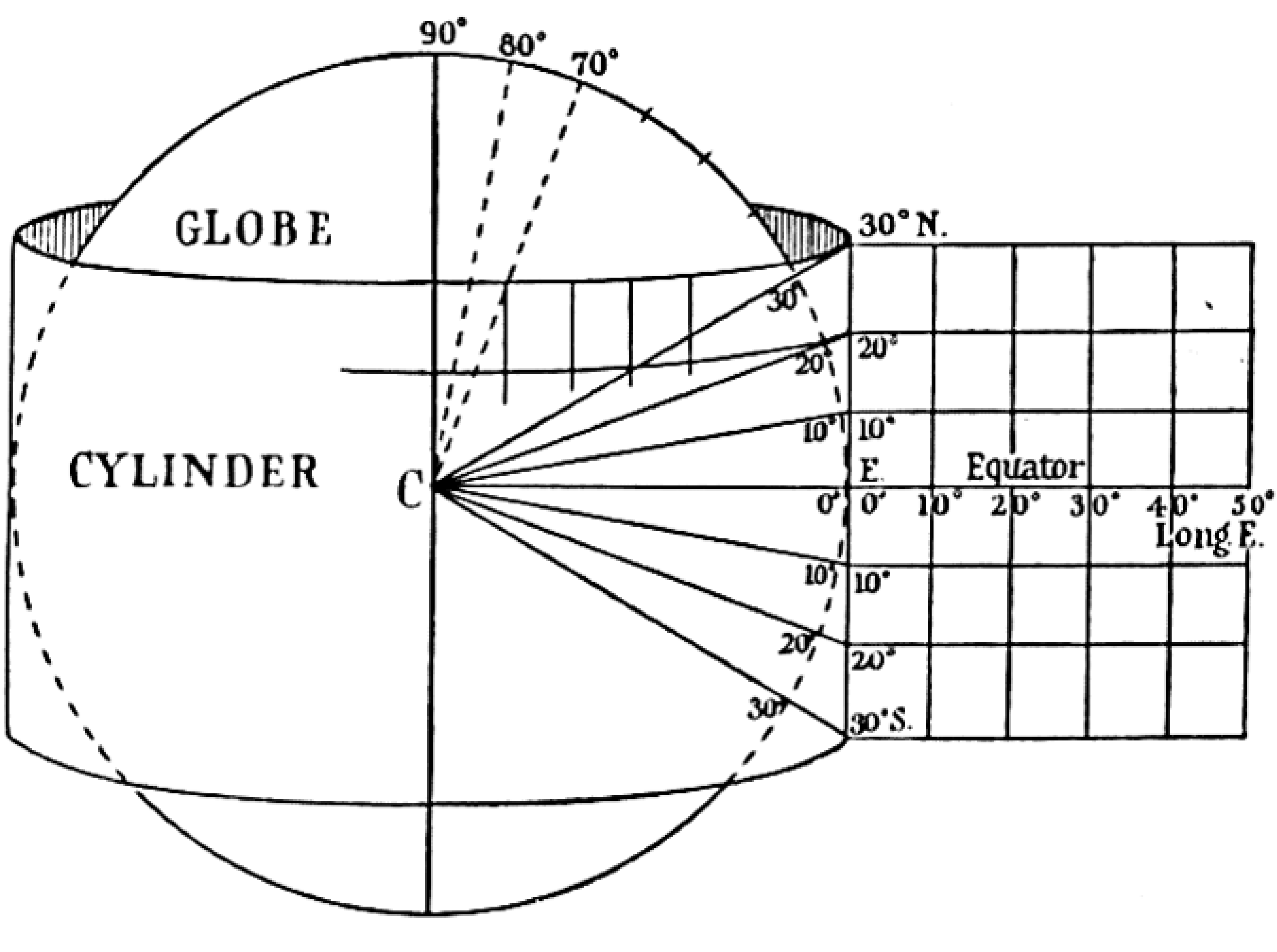
$$= 12{\cdot}32 \text{ inches.}$$

This is one of the most useful projections for representing limited areas. In the latest atlases it is much used for maps of Europe and the countries of Europe. It is also employed for topographic maps, but is not suitable for extreme latitudes, as the pole is again represented by an arc. It is an easy projection to draw if the scale is not too large. Otherwise the centre of the parallels might be at some distance outside the map, so that there would be great difficulty in describing arcs of large radius and more difficulty in drawing meridians to cut in a point at a considerable distance away.

Another modification is known as *Bonne's modified conical* map. It is not in reality a conical projection, since the meridians are not represented by straight lines, but by curved lines which have to be plotted. This method improves on the simple conical with one standard parallel, the scale of which is correct along all the meridians and along the standard parallel, but which is more and more incorrect along the other parallels as the extent of latitude increases. After the parallels have been divided correctly the meridians are formed by drawing curves through the corresponding points on the parallels. It is obvious that it is an equal-area projection. Distortion of shape increases away from the central meridian, only along which is the scale correct. It is not a suitable projection for the polar regions or for countries covering a wide range of longitude. It is used chiefly for countries covering a wide limit of latitude. It is very common in atlas maps —for example, of France and Russia—and is also used for Ordnance Survey maps of Scotland and Ireland on scales of 1 inch to 1 mile and less.

A particular case of Bonne's projection, having the equator as standard parallel, is the *Sanson-Flamsteed* projection. The parallels are straight lines at an equal distance apart. The central meridian is a straight line, but the others are curved and converge toward the poles. This projection is used in atlas maps for areas which extend almost equally on both sides of the equator and have not a great extent in longitude. A good example of this is supplied by the map of Africa. It is also used for a general map of Australia and Polynesia, although the longitude is too great, and sometimes for South America, which does not extend far enough north of the equator.

3. **Cylindrical Projections.** To understand what is meant by a cylindrical projection imagine a sheet of

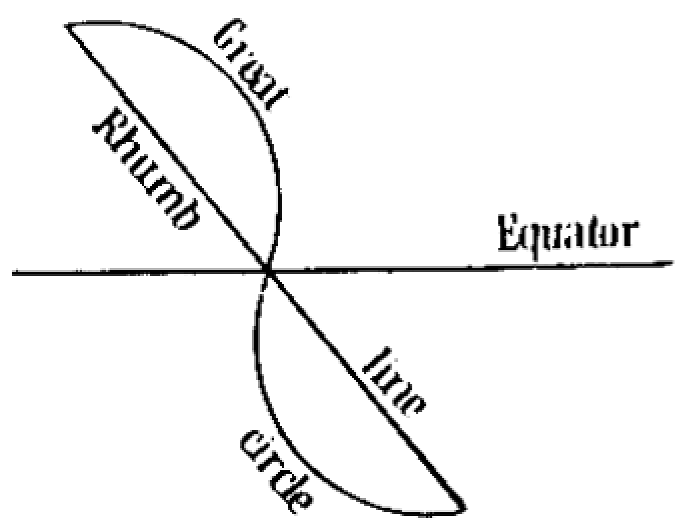


paper in the form of a cylinder wrapped round the globe, and with its axis parallel to the axis of the globe. Then the meridians of longitude and the parallels of latitude develop into straight lines at right angles to

each other. The meridians cut the equator at their correct distances apart (drawn to scale).

Although meridians actually converge toward the poles they are seen as parallel straight lines on the cylindrical projection, so that the pole itself appears as a straight line of the same length as the equator.

One of the most important of the cylindrical projections is *Mercator's*. It is orthomorphic—that is, shows the correct shape of every small feature. Mercator's map was first used for coastal navigation because of a very important property which it possesses. If a straight line be drawn on the map between two places it will cut all the meridians at the same angle. In other words, *bearings* on the map are correct. Thus it is only necessary to join two points on the map and find the bearing (by protractor) in order to get the true course from one to the other. The straight lines joining the points are called *rhumb lines* or *loxodromes*. They do not, however, represent the shortest route, which is the *great circle* distance between the points. In modern times navigators use as far as possible the great circle course. In the Northern Hemisphere this lies to the north and in the Southern Hemisphere to the south of the compass course.



This is done by sailing on a series of short rhumb lines, which are really chords of the great circle. It is not necessary, in this way, to be always changing the course, although the shorter the rhumb lines, the oftener has the course to be changed. But, on the other hand,

the shorter the rhumb lines, the less departure is there from the great circle. The navigator is assisted by mapped-out directions of the more familiar ocean routes, which provide him with actual worked-out rhumb courses giving distances and bearings. Ruler and protractor only are then necessary to plot his route.

Mercator's map is not suitable if areas have to be compared. As the latitude increases, east to west distances become much greater than they ought to be. The scale of longitude becomes more and more exaggerated as the latitude becomes greater, so that the distance between successive parallels increases rapidly with the latitude. At latitude 60° the meridians are twice as far apart as they should be. The poles are at an infinite distance away and cannot therefore be shown, so that in maps of the world on this projection the polar regions are left out usually from about 83° north and 75° south. An atlas map of the world on Mercator's projection shows countries such as Siberia, Greenland, and the northern parts of Canada much distorted in shape and exaggerated in size. Mercator's is therefore unsuitable for a land map. For marine charts, however, it is most valuable.

For small maps of the world on a single sheet a useful projection which is often used is *Mollweide's homolographic* projection. Being an equal-area map, it is suitable for distribution maps. It has a neat shape in the form of an ellipse, with the equator, as the major axis, twice the minor axis from pole to pole. The parallels are straight lines which get closer toward the poles. All the meridians except the central one and one other, which is a circle, are ellipses. The Mollweide is an excellent projection for maps of a hemi-

sphere, and is extremely useful for climate charts and distribution diagrams. Compared with the Sanson-Flamsteed projection there is little compression near the poles, although the length of the meridians and their inclination to the parallels close to the margins of a world map are even more exaggerated.

The projections used in two school atlases may be analysed as follows:

HARRAP'S GENERAL SCHOOL ATLAS

The World	Lambert's Zenithal (or Azimuthal)
	Gall's Cylindrical
Europe	Bonne
British Isles	Conical
Asia	Bonne
	Conical (with two standard parallels)
Africa	Sanson-Flamsteed
North America	Bonne
	Conical
South America	Bonne
	Sanson-Flamsteed
Australia	Bonne
New Zealand	Conical

PHILIP'S MODERN SCHOOL ATLAS OF COMPARATIVE GEOGRAPHY

Europe	Bonne
	Conical (with two standard parallels)
Asia	Bonne
	Conical (with two standard parallels)
	Zenithal
Africa	Bonne
	Sanson-Flamsteed
North America	Bonne
	Zenithal

South America	Sanson-Flamsteed
Australia	Bonne
	Sanson-Flamsteed
New Zealand	Conical (with two standard parallels)
	Sanson-Flamsteed
Oceania	Sanson-Flamsteed
Polar Regions	Zenithal
The World	Zenithal
	Mollweide
	Cylindrical

CHAPTER IV

HILL FEATURES

It has been shown to be possible, with varying degrees of accuracy, to plot on paper parallels and meridians to form a map of the earth or of some portion of it, after which places can be inserted and the lines of communication between them shown. The impression produced by such a map is that the country depicted is perfectly flat. No account is taken of the unevenness of the surface of the earth. This uneven nature of the ground, which is known as surface relief or configuration, has to be shown by indicating on the map the height and shape of all hill features. A thorough knowledge of the methods used and the various problems arising from them provides a proof of proficiency in map-reading. Broadly speaking, hill features are represented on the map by:

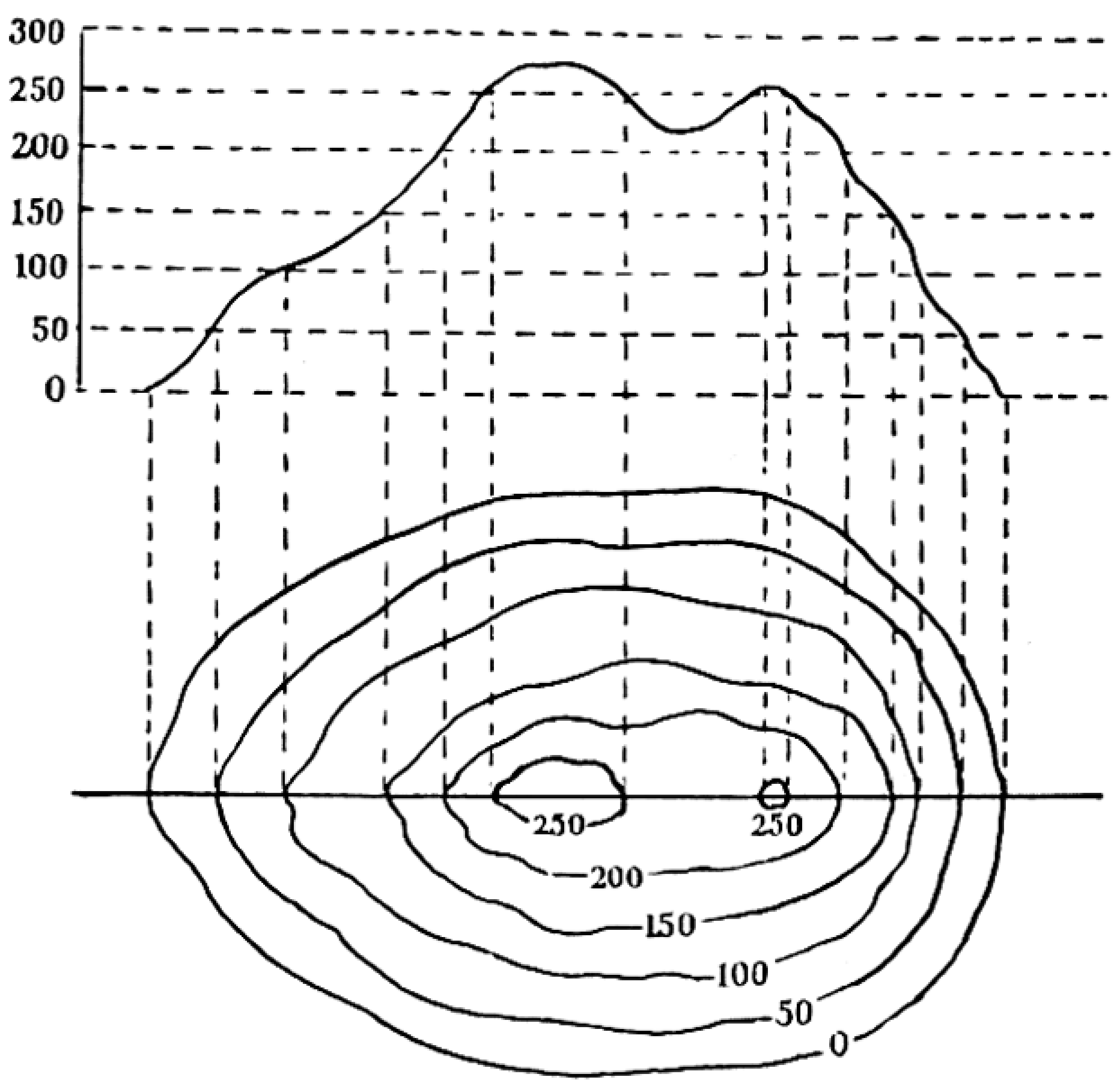
1. Contours.
2. Hachures.
3. Hill-shading.
4. Colour layers or layer-colouring.

These methods are not all suitable for atlas maps.

1. **Contours.** Underlying every method of indicating surface relief is the idea of joining all points on the ground in the same horizontal planes. Thus is derived the notion of a *contour*, which is a line drawn on a map through all points at the same altitude. Expressed otherwise, it is the irregular boundary of a horizontal plane at a definite height above mean sea-

level. It is obvious that a contour must be a closed curve. The principle of the contour system may be illustrated graphically.

In the upper portion of the diagram a hill is shown in section—that is, as if cut by a vertical plane—with the different heights shown across it by straight lines,



each one representing a height 50 feet above the previous one. In the lower portion the hill is shown in plan—that is, as if cut by horizontal planes, in this case 50 feet apart. The whole series of plans superimposed gives a contoured plan of the hill.

Imagine the coast or shore-line to be the first, or zero, contour. Then a rise of 50 feet in the sea will produce a new shore-line, 50 feet higher than the first, and corresponding with a contour 50 feet above mean sea-level. A further rise of 50 feet will reach the 100-feet

contour, and so on at convenient intervals. Sea-level is taken as approximately mean sea-level at Liverpool, and is known as *Ordnance datum*. Unless it serves a useful purpose to take this level as zero contour, as, for example, in a field sketch, any new datum may be taken from which heights can be measured. The Ordnance datum is necessary to show the 'absolute' vertical height above mean sea-level, whereas an assumed level admits of only 'relative' heights being compared.

The contour system of showing heights is the most accurate and satisfactory, especially if combined with *spot-heights*, which record on the map the exact height of some of the principal summits. Spot-heights are also shown by figures, *e.g.*, 140, along the main roads, or by the sign of a triangulation station, 312′ △ or △312′, or by a bench-mark, ↑ B.M. 144·25.

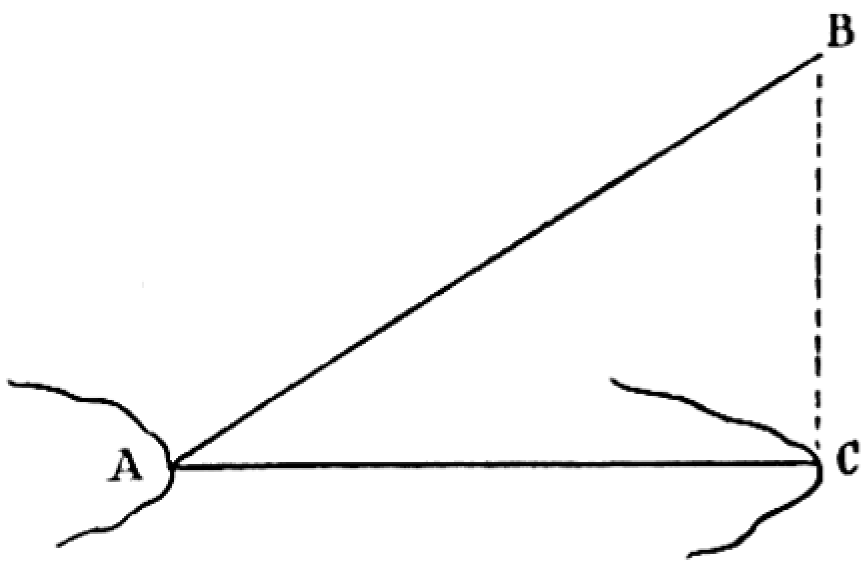
The height of one contour plane above another, or the vertical distance between successive contours, is called the *vertical interval* (V.I.). This interval should remain constant for the same map. Its actual size is important, because the degree of completeness with which contours represent the configuration of any piece of ground depends upon the vertical interval between the lines—the smaller the interval the more complete the representation.

The appropriate contour interval for any map depends on the nature of the ground and the purpose for which the map is intended. For example, on a map of a very high mountain system a 10-feet vertical interval would so crowd the contours as to make them impossible to read, and therefore useless. On the

contoured Ordnance maps contours are generally at intervals of 50 or 100 feet, varied by intervals of 250 feet or multiples of 100 feet. On the large-scale Ordnance maps of Great Britain contours are shown for every 100 feet. When contours are drawn sufficiently close together and can be easily read they serve not only the purpose of actual measurement, but at the same time form a system of hill-shading which gives at a glance a good idea of the physical features depicted.

It must not be forgotten in reading a contoured map that the map affords no information about the ground between two contour-lines, except in the most general way. If there is a vertical interval of 100 feet any point between the 100-feet and 200-feet contours may be 101 feet or 199 feet. In order to give a more detailed idea of the intervening ground auxiliary contours, or *form-lines*, are sketched in by hand to indicate special features.

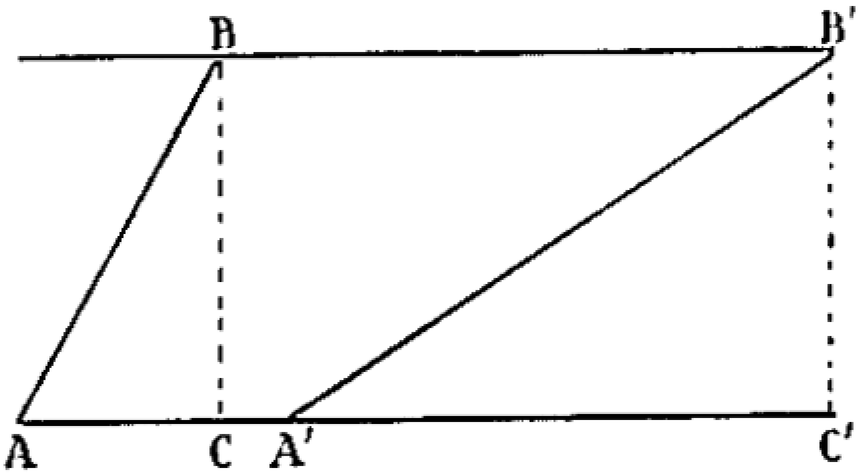
The distance measured on the map between successive contours does not represent the actual ground distance, but merely the distance in plan, and is known as the *horizontal equivalent* (H.E.). In representing hilly country on a flat surface it is necessary to reduce all distances measured on a slope to their horizontal equivalents. Thus distances measured along a hilly road are greater than the corresponding distances obtained from the map.



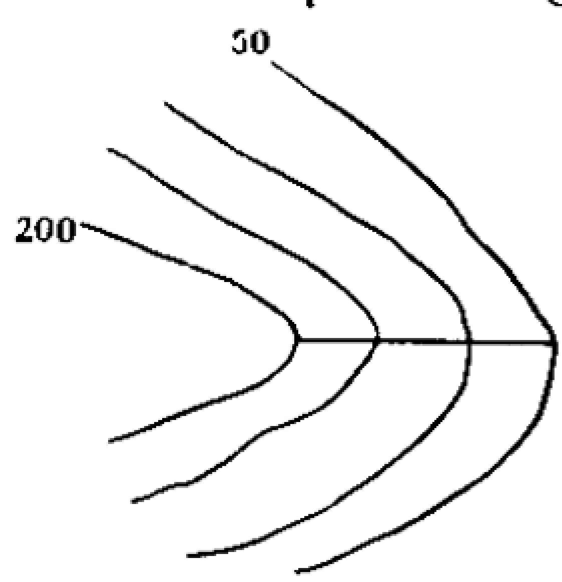
AB, representing an actual road, is shown on the map by the distance AC.

Contours and Slopes

AB and A′B′ represent two actual roads, the slope of AB being steeper than that of A′B′. The corresponding distances between the contours are represented by AC and A′C′. Since AC is less than A′C′ it follows that the steeper the slope the closer together are the contours. If the slope of AB were vertical, as, for example, in a precipice, the projection of AB would vanish, so that the contours would run into one another, separating and diverging where the precipice ended. A level plain, on the other hand, would have no contours at all—or at least, they would be at an infinite distance apart.



Slopes are reckoned directly across the contours along the steepest line. This direction, along which water would flow, is called a *stream-line*. Where contours are irregular it is often a difficult matter to follow the directions of stream-lines, and their study cannot by any means be neglected in practical map-reading if proficiency is to be acquired.



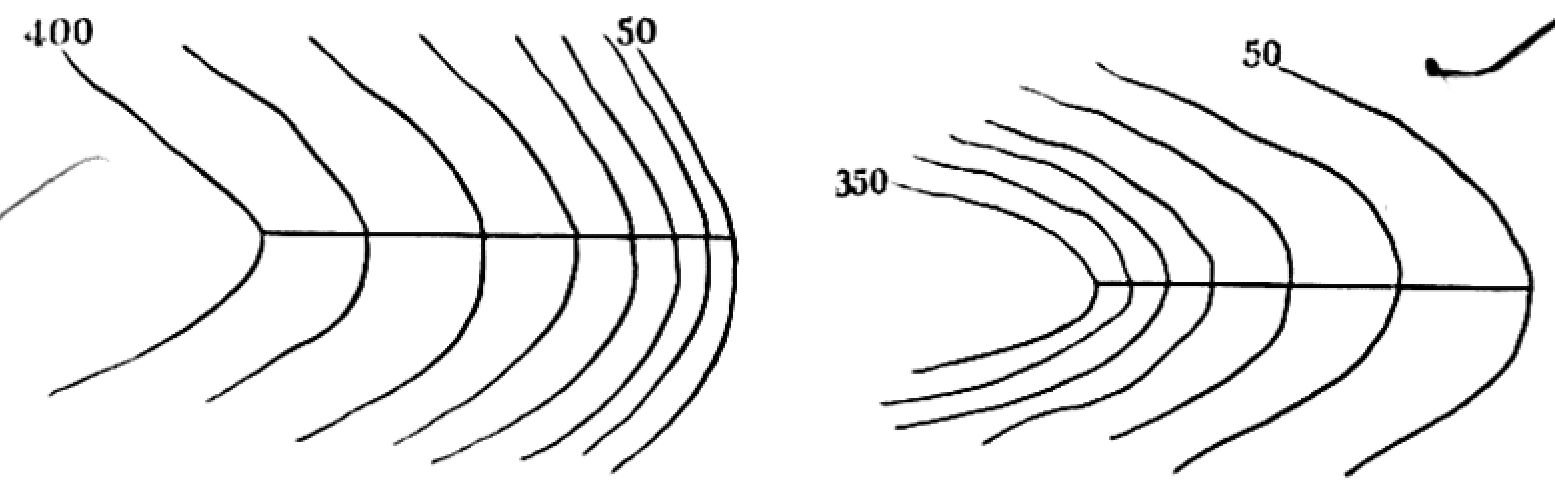
UNIFORM

Kinds of Slope

(*a*) *Uniform*. When the contours are evenly spaced.

(*b*) *Convex*. When the space between the contours decreases toward the lower ground.

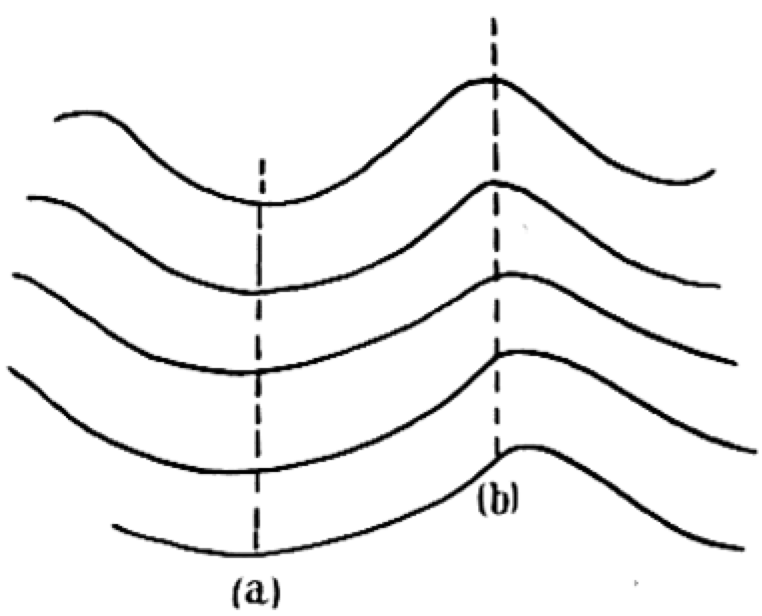
(*c*) *Concave*. When the space between the contours increases toward the lower ground.



(*d*) *Undulating*. A series or combination of the above slopes.

Contour Features

(*a*) *Salient* (*spur* or *bluff*). A tongue of land projecting from a hill-side, shown on the map by the contours running outward from the main feature.



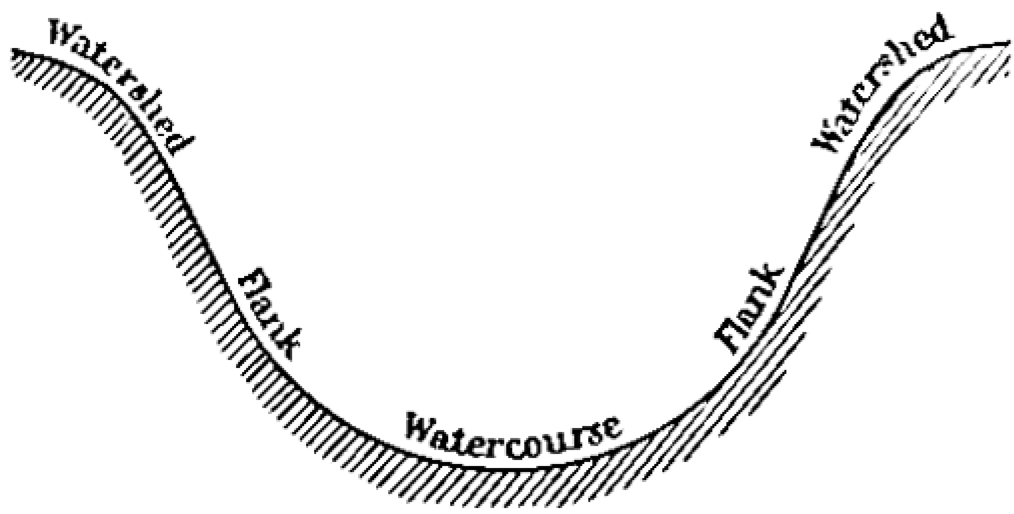
(*b*) *Re-entrant*. A valley or depression on the side of the main feature. Its position is between two salients, and is shown on the map by the contours bending inward.

(*c*) *Ridge-line*. The crest of a hill. It marks the line of water-parting, or 'parting of the waters,' from which water flows in opposite directions.

(*d*) *Watershed*. A line of water-parting, or 'divide,' which forms a boundary of drainage areas.

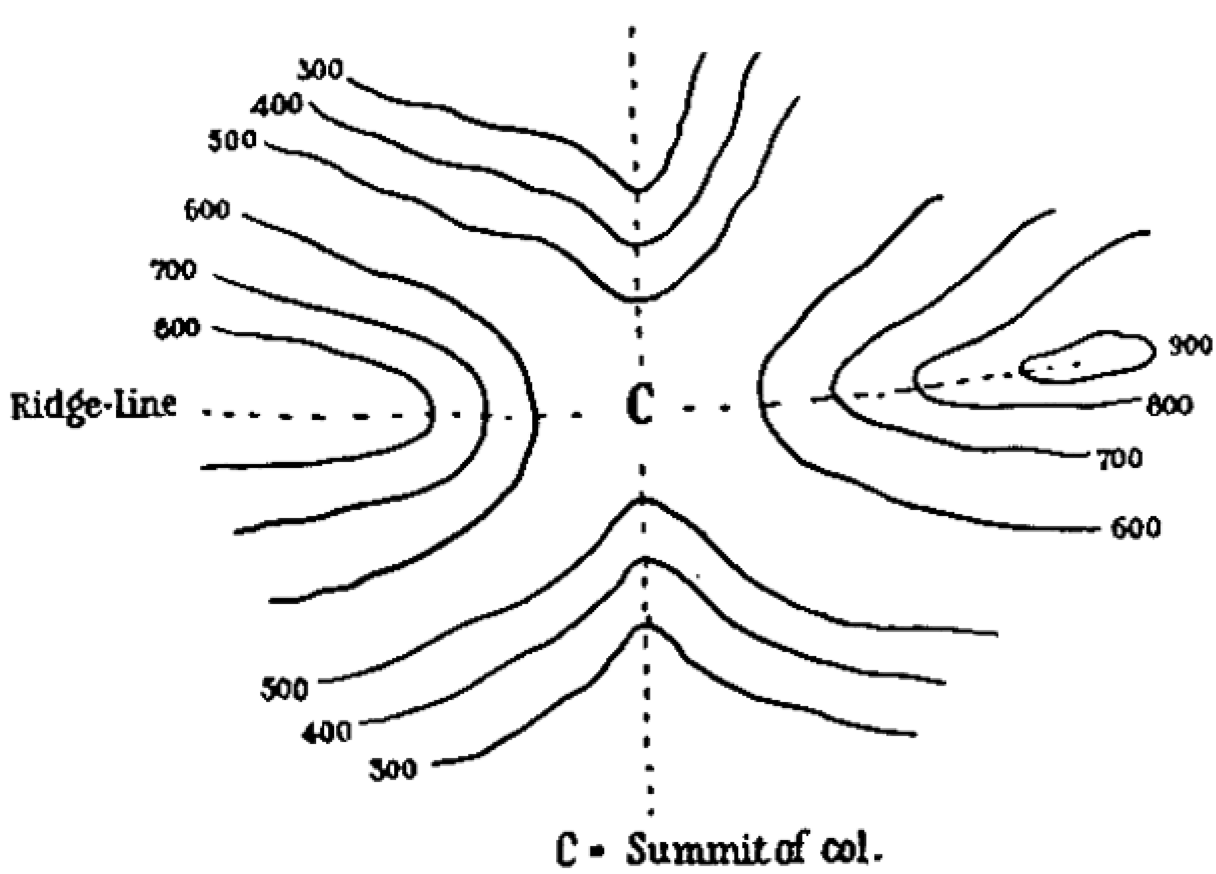
(*e*) *Valley*. That part of the ground contained between two slopes converging at their bases.

(*f*) *Watercourse*. The line in a valley along which two converging slopes unite. It is usually the course



of a stream. The slopes on either side of the watercourse form the flanks of the valley.

(*g*) *Col*. A more or less marked depression through which the ridge-line passes to connect the summits of a chain of heights. A col, from its comparatively low



level, affords the best passage through a chain of mountains, just as a watercourse through a valley.

(*h*) *Plain*. Land, generally near the sea, which pre-

sents only a slight undulation of surface. If it occurs at a considerable height above sea-level, with the land falling away abruptly from its margins, it is called a *plateau*.

(*i*) *Knoll*. A low, detached hill.

Points to be noted in studying Contours

(1) A small ring contour, with no contours inside it, denotes a summit.

(2) The closer the contours the steeper the slope.

(3) A small triangle accompanied by a figure, inside a ring contour, denotes the actual summit.

(4) As contours cannot be numbered very frequently, for fear of overloading the map, great care must be taken that the correct number is given to each contour.

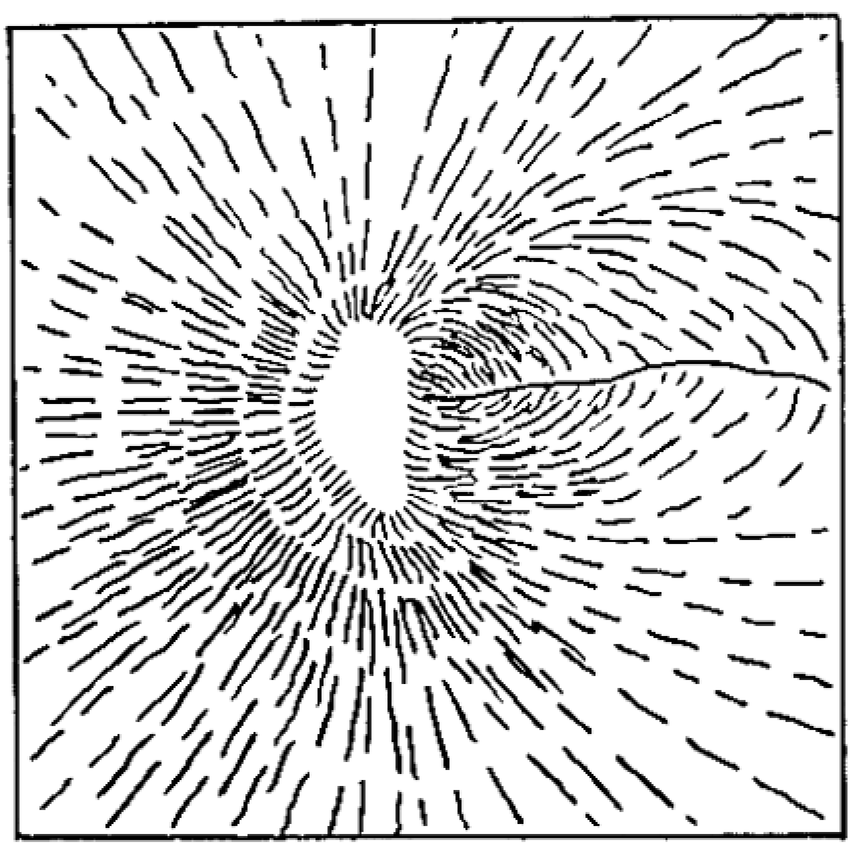
(5) A contour shown by dotted lines is known as a form-line. These often occur at the top of a hill where the surface is rather flat above the last contour line.

(6) On some maps the heights of certain points, generally along roads, are given. These heights correspond to those of bench-marks, which are generally indicated by a mark cut on a fixed stone or wall.

2. **Hachures.** If a clear impression of the relief of a region is to be got from a map it is necessary to show more than contours, for these, while affording a good general idea of the nature of the ground, fail to furnish information regarding the surface between successive contours. In large-scale maps with a small vertical interval this does not matter much, but in small-scale maps where the vertical interval is considerable interpretation is difficult except after long practice. Contoured maps do not appeal quickly to the eye, but

require some mental effort to be appreciated. It is desirable, therefore, to make a map explain itself more definitely. To obtain this result two considerations are possible. Either the slope of the ground must be of the first importance, with the height of the ground above sea-level subsidiary, or the height must be considered of first importance and the slope left to the imagination.

If the slope of the ground is of primary importance series of stream-lines are drawn on the map at distances



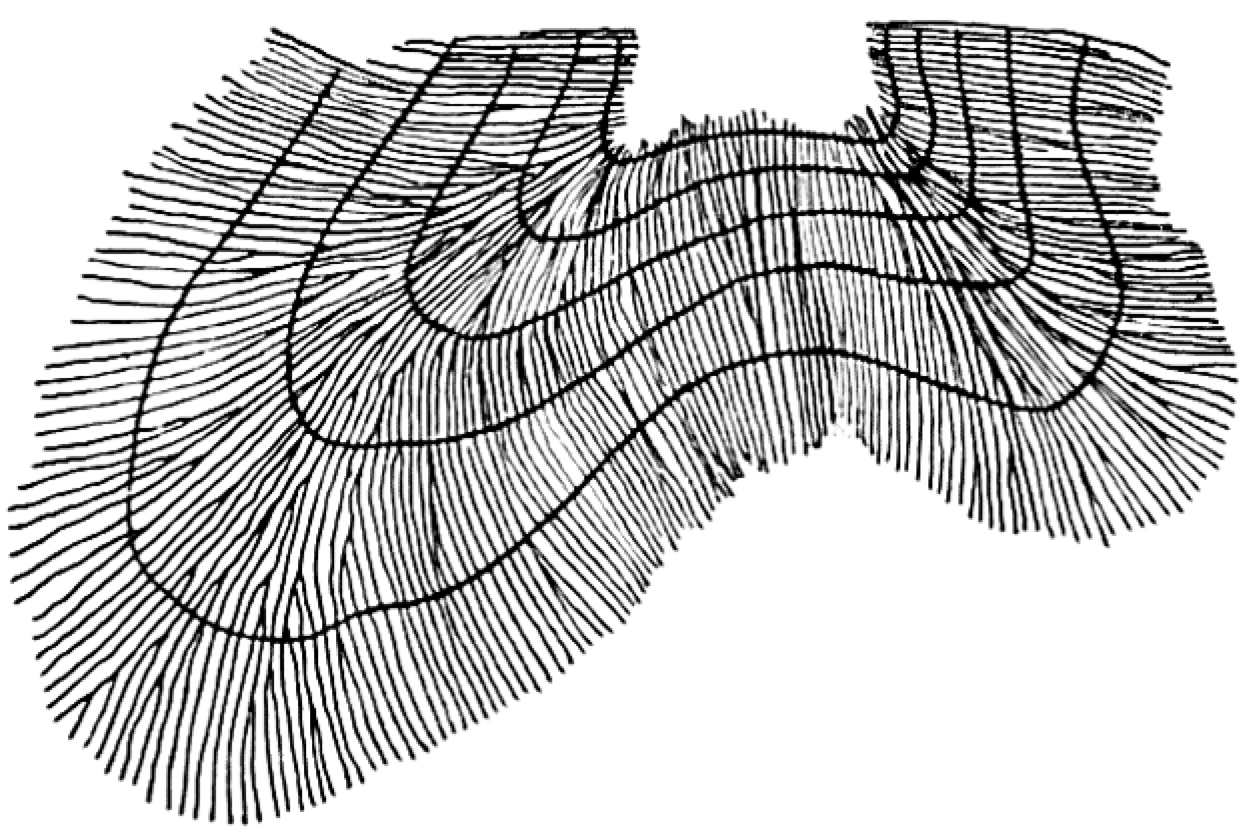
apart proportional to the actual distances, and of a thickness proportional to their slope—*i.e.*, the steeper the slope, the closer and thicker the stream-lines are drawn. These short, disconnected stream-lines, which, as we have seen, are the lines of greatest slope, are called *hachures*, and are drawn at right angles to the direction of the contours at any point.

Slight slopes, on which stream-lines are drawn thin and wide apart, become lighter and lighter until, when practically horizontal, they contain no stream-lines and appear white. When relief is depicted by hachuring

alone white lines take the place of the contours, showing where the hachures have been interrupted on crossing them.

Hachures alone convey a very clear impression of the distribution of the hill features of a country and its slopes, but do not record actual heights above sea-level. Thus numerous spot-heights are necessary. The reverse is true of contours. In very hilly areas hachuring may sometimes become so strong as to obscure the other detail of the map.

When the vertical interval is large the addition of hachures to a contoured map is valuable in showing



minor features which the contour lines fail to show, and provides a good example of hill-shading, although the latter may be employed as a distinct method of representation.

A good example of a contoured map supplemented by hachures is the '1-inch' Ordnance Survey "Fully Coloured" edition of Great Britain, the hachures being shown in brown and the contours, at 100-feet vertical interval, in red. This series is not being reprinted, but

has given place to the "Popular" edition, contoured at a 50-feet vertical interval, which has become the standard '1-inch' map of Great Britain.

3. **Hill-shading.** As a distinct method of showing hill features, hill-shading is based on the effect produced by light falling over the country, either vertically or obliquely, the practical application of which is the use of dark shades for steep slopes and light shades for gentle slopes.

(*a*) **Vertically.** It is obvious that the top of a hill, if flat, will receive the maximum of light, and consequently will be left white on the map. Similar treatment is applied to valleys and any flat portions of country. Further, the indication of a stream on an unshaded area is sufficient to determine whether the land is high or low-lying. With an increase of slope the intensity of light decreases, so that both sides of a hill or range of hills will be dark. In general principle the procedure is analogous to hachuring.

(*b*) **Obliquely.** Here it is necessary to imagine the rays of light emanating from one side of the area, generally the north-west. Thus the eastern and southern slopes of hills are in shadow. In order to read a map which is shaded in accordance with the principle of light received from an oblique direction place it in similar relation to a window as the assumed source of light. The new "Relief" '1-inch' map has oblique illumination.

Hill-shading is generally used for small-scale maps in which it is impracticable to express the relief adequately by contours. Contours may, however, be supplemented by hill-shading, the combination producing a very satisfactory map. A good example is

the 'half-inch' Ordnance Survey map, certain sheets of which are available with hills shaded in colour. This coloured hill-shaded edition is giving place to the new layer-coloured edition in which contours are shown in brown with a 100-feet vertical interval.

A map of the United Kingdom which dispenses with contours is the $\frac{1}{1,000,000}$, or 15·782 miles to 1 inch, map, in which hills are shaded in brown and coastal waters in blue.

4. **Colour-layers or Layer-colouring.** When height above sea-level is the chief consideration in delineating the relief of a country a method known as *layer-colouring* is employed. This is a graphic method which consists in giving the intervals between successive contours a distinctive colour or shade. Generally green is the colour used for all land immediately above sea-level, followed by a lighter shade of green, after which brown is used, increasing in intensity as the higher ground is reached. Crimson and sometimes white are also used for very high ground. Blue, increasing in strength with the depth, is used for the sea. Different arrangements of colour may be employed, but the principle remains the same—namely, gradations of colour to represent differences of height. With the addition of colour to a contoured map a very vivid picture is given of the general distribution of high and low ground, with the information comparatively definite and accurate.

An excellent example of the use of layer-colouring is found in Bartholomew's 'half-inch' cycling map of Great Britain, in which dark green is used to colour regions below the 100-feet contour, followed by different shades of the same colour up to 400 feet, after

which gradations of brown are used. The Ordnance Survey has also a layer-coloured 'half-inch' map.

The Ordnance Survey physical map of England and Wales on the scale of $\frac{1}{1,000,000}$ (15·782 miles to 1 inch) has contours at 50, 100, 200, 400, 800, 1200, and 2000 feet and orographical colouring in red, brown, and green, the latter for the lower levels and red and brown for the higher. Additional contours and colouring for 3000 and 4000 feet are used for the uniform edition of the physical map of Scotland.

But, although the important question of height above sea-level is vividly solved by the colour scheme, slope can only be inferred from the comparative width or narrowness of the colour strips. And, since the contours become numerous and close when the range of altitude is considerable, the variety of colours available may become exhausted. All detail may be obscured too in very high country by the darkness of the layer tints. To obviate these difficulties the vertical interval may be changed, but in order to avoid confusion it is usually preferable that the vertical interval should remain constant for the same map. For example, in the "Fully Coloured" '1-inch' map the vertical interval after 1000 feet is changed from 100 to 250 feet.

A very useful edition of the '1-inch' map is the tourist edition (Ordnance Survey), which consists of sheets showing popular tourist resorts and districts of special interest. Contours are shown at intervals of 50 feet, and physical features are represented very clearly by layer-colouring. In some of the earlier issues hachuring is employed. In addition to the relief much useful information is given on the face of the map.

Eight sheets are available for Scottish districts and sixteen for English.

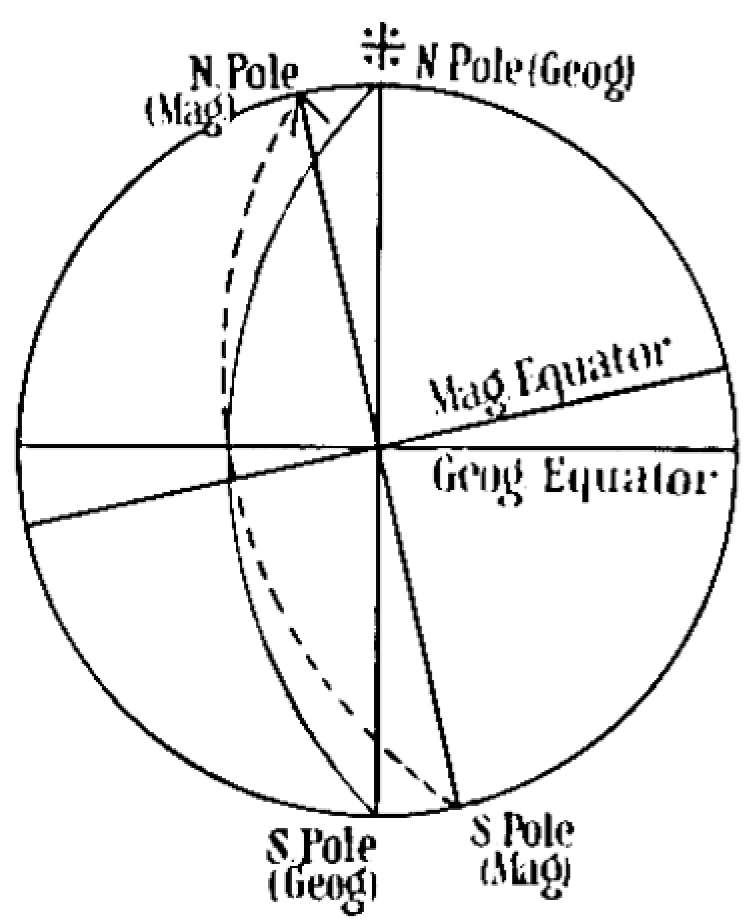
EXERCISES

1. Define: contour, datum, ridge-line, col, spot-height, V.I., H.E., watershed, salient, and bench-mark.
2. Describe briefly: (*a*) hachures, (*b*) layer-colouring.
3. What advantages have contours over other methods of showing relief?
4. When, if ever, does the V.I. vary? Give reasons.
5. How is a valley recognized on a contoured map? Illustrate by a diagram.
6. Illustrate by contours the varying nature of slopes.

CHAPTER V

TRUE AND MAGNETIC NORTH

THE earth may be considered as a great magnet. The behaviour of a compass needle will illustrate its magnetism. When the needle comes to rest it will be seen to have arranged itself along a definite line, which does not correspond with the meridian through the north and south geographical poles, fixed points which mark the extremities of the polar diameter, about which the earth rotates daily. This shows that the geographical poles of the earth and the magnetic poles, although they are near each other, do not coincide. The magnetic and the true meridians cut one another at an angle which varies in size at different places on the earth's surface. This angle between the geographical and the magnetic meridians at any place, or, simply, the angle between true and magnetic north, is called the *variation of the compass* or *declination* at that place. The variation is said to be east or west according as the needle points east or west of true north.



Variation is not a constant quantity. It depends on one's position on the earth's surface. For example, at the present time, over almost all Europe, Africa, and

the Atlantic and Indian Oceans the needle points west of north, while over most of Asia, America, and the Pacific Ocean it is east of north.

There is no record of magnetic variation previous to about 1580, when the variation of the magnetic needle was first measured at London. The needle then pointed about 11° 17′ to the east of true north, which is the greatest recorded easterly variation. From that time till about 1657 this easterly variation diminished until the true and magnetic meridians coincided. A westerly variation then began, and reached a maximum of 24° 38′ in 1818.

Subsequent to that date the variation has diminished, the magnetic north line approaching the true north line by six to nine minutes annually, a comparatively small rate of change. In 1900 the variation for Kew was 16° 52·7′ west. Since 1905 there has been a very distinct acceleration in the rate of change over most parts of Europe.

The values for 1929, 1930, and 1931 were 12° 35·8′ west, 12° 24′ west, and 12° 13·5′ west respectively. It may be mentioned here that the work of recording earth magnetism was transferred in 1925 from the Royal Observatory, Greenwich, to Abinger, near Dorking.

There is also a daily change in the variation, greater in summer than in winter. At Abinger, for example, at the present time, the compass needle in summer moves about twelve minutes to the west and in winter about seven minutes. The mean position is reached about 10 A.M. and again about 6 P.M. The most westerly and easterly positions are early afternoon and during the night respectively.

Position of Magnetic Poles

In 1928 the position of the magnetic poles was approximately:

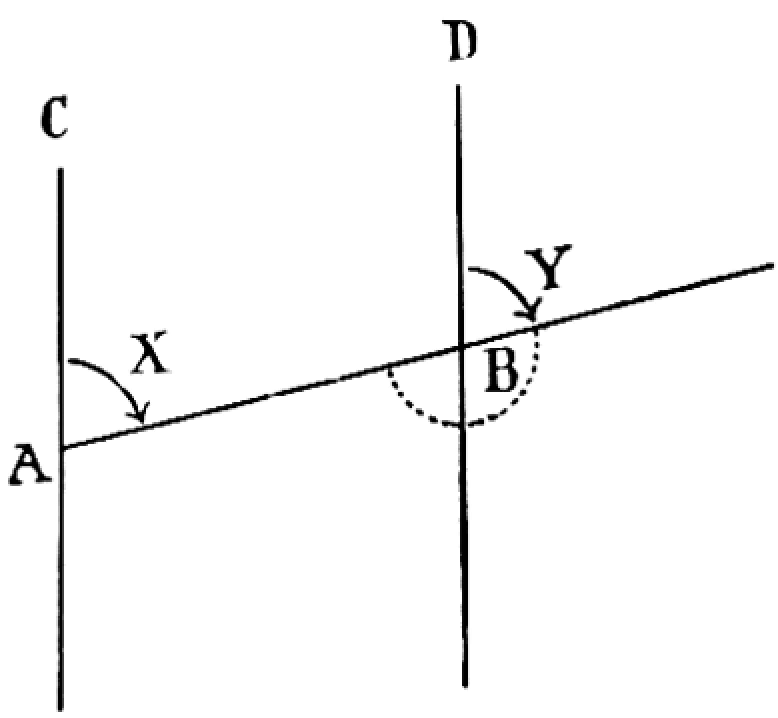
	Latitude	Longitude
North magnetic pole . .	71° north	96° west
South ,, ,, . .	73° south	156° east

Sometimes there is a deviation of the compass needle from its normal position owing to the presence of magnetic iron ore or of iron in its neighbourhood. This is known as *local magnetic attraction.*

CHAPTER VI

BEARINGS

THE bearing of an object is simply its direction. In practice it is the angle between some fixed line (generally a magnetic meridian) through the observer's position and the line from the observer to the object. It is measured in a clockwise direction up to 360°.

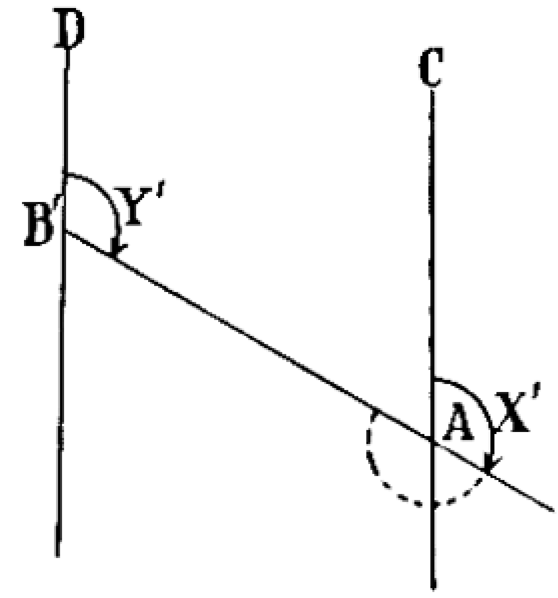


AC and BD represent the true north directions from A and B respectively, AC being therefore parallel to BD.

Let the observer be at station A and look in the direction of station B, on his right. Then the angle X is the 'bearing of B from A or from A to B.' Since A is the starting-point the bearing X is known as a 'forward bearing,' being the direction from one station, A, to the next in succession, B.

If the observer be now at station B and look back toward station A, the original bearing, X, is increased by 180°, the new bearing representing the 'bearing of A from B or from B to A.' It is the 'back bearing' corresponding to the original forward bearing, since it measures the direction of a station which has been passed. From the diagram it is obvious (by geometry) that angles X and Y are equal, since they are the in-

terior opposite angles formed by a straight line cutting two parallel straight lines. Hence, if the forward bearing, X, is 77° the corresponding back bearing, Y, is 77° + 180°—*i.e.*, 257°.



With A again as starting-point and the observer looking toward B′, on his left, the bearing of B′ from A, or the forward bearing, is measured by angle X′ + 180° —say 300° altogether. Therefore angle X′ measures 120°. Angle Y′, the corresponding back bearing, represents the bearing of A from B′ and is equal to angle X′—*i.e.*, 120°.

Briefly, the following result has been reached:

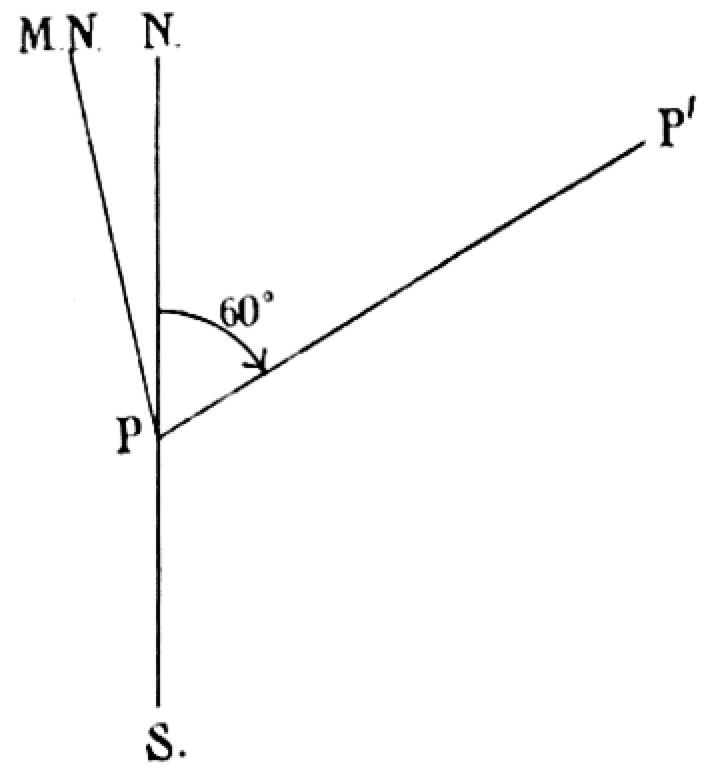
(*a*) Forward bearing 77°; backward bearing 257°.
(*b*) Forward bearing 300°; backward bearing 120°.

If the forward bearing is less than 180°, as in (*a*), add 180° to get the corresponding back bearing. If the forward bearing is greater than 180°, as in (*b*), deduct 180° to get the corresponding back bearing.

Plotting and measuring Bearings

This is done by means of a protractor, the semicircular variety of which is very suitable. The protractor is placed with its diameter vertical—north-south—so that by placing it on the right of one's position bearings up to 180° can be plotted or measured, whereas by placing it on the left of one's position the bearings plotted or measured must be between 180° and 360°.

Measuring Bearings. The bearing of P′, on the right of one's own position, P, is required. Place the protractor on the right of P and read the angle indicated (diagram)—*e.g.*, 60°. This is the bearing of P′, and since it is measured from true north it is a true bearing.



To convert it into a magnetic bearing add or deduct the variation, according as it is west or east of true north respectively.

In this case, given the variation as $12\frac{1}{2}°$ west, the magnetic bearing of P′ is $60° + 12\frac{1}{2}° = 72\frac{1}{2}°$.

If P′ is on the left of P place the protractor on the left, and the inner set of figures will give the required bearing, which can then be converted into a magnetic bearing as above.

Exceptional Cases

(Variation of compass $12\frac{1}{2}°$ west.)

1. If the position is on the north-south line and north of the observer its bearing is 0°. From magnetic north the angle is $12\frac{1}{2}°$.

2. If the position is on the north-south line and south of the observer its bearing is 180°. From magnetic north the angle is $180° + 12\frac{1}{2}° = 192\frac{1}{2}°$. Since this bearing is greater than 180° it is more usual to express it as left of magnetic north, the angle now being measured in an anti-clockwise direction from the meridian. Expressed in this form the bearing is

$$360° - 192\frac{1}{2}° = 167\frac{1}{2}° \text{ left.}$$

3. If the true bearing of a position is $167\frac{1}{2}°$ the magnetic bearing is $167\frac{1}{2}° + 12\frac{1}{2}° = 180°$, right or left, the position being south of the observer. If the true bearing is greater than $167\frac{1}{2}°$ the angle from magnetic north is 'so many degrees left.' In other words, assuming the variation to be west, if the true bearing is greater than 180° minus the variation, the angle from magnetic north is left.

4. If the true bearing of a position is $347\frac{1}{2}°$ the magnetic bearing is $347\frac{1}{2}° + 12\frac{1}{2}° = 360°$ or 0°, the position being on the magnetic north-south line north of the observer. The angle from magnetic north is zero. In general, if the true bearing is greater than 360° minus the variation, the angle from magnetic north is 'so many degrees right.'

E.g., true bearing = 350°.

$\therefore$ magnetic bearing $= 350° + 12\frac{1}{2}° = 362\frac{1}{2}°$.

$\therefore$ angle from magnetic north $= 2\frac{1}{2}°$ right.

Plotting Bearings. The protractor is used with its diameter vertical, as in measuring bearings, but if a magnetic bearing is given the variation must first be deducted to give the true bearing.

Plotting a March given Bearings and Distances

This problem consists of two parts:

(*a*) Plotting bearings.

(*b*) Measuring distances and bearings.

The methods of plotting and measuring bearings have already been indicated. To measure the distance of a position the best protractor to use is the rectangular service protractor, which has several scales of yards

marked on it. One of these is the $\frac{1}{20,000}$ scale, from which distances up to 4000 yards may be read. Distances greater than 4000 yards must be measured by applying the protractor scale as many times as are necessary. The range between two points may also be measured by transferring the length between them, marked on a piece of paper, to the accompanying scale of yards on the map.

Problem. Start from A (a position on the map) on a compass bearing of 66° and proceed for 1000 yards. Then go on a bearing of 240° for 1500 yards. Find your destination and also its distance and bearing from the starting-point. Scale of map $\frac{1}{20,000}$, variation $12\frac{1}{2}°$ west.

Method. Draw a true south-north line on the map through A. At A draw a line making an angle of $53\frac{1}{2}°$ $(66° - 12\frac{1}{2}°)$ with this line, and measure off in this direction 1000 yards from A (1·8 inches). This gives the point B, which is the starting-point for the second part of the march.

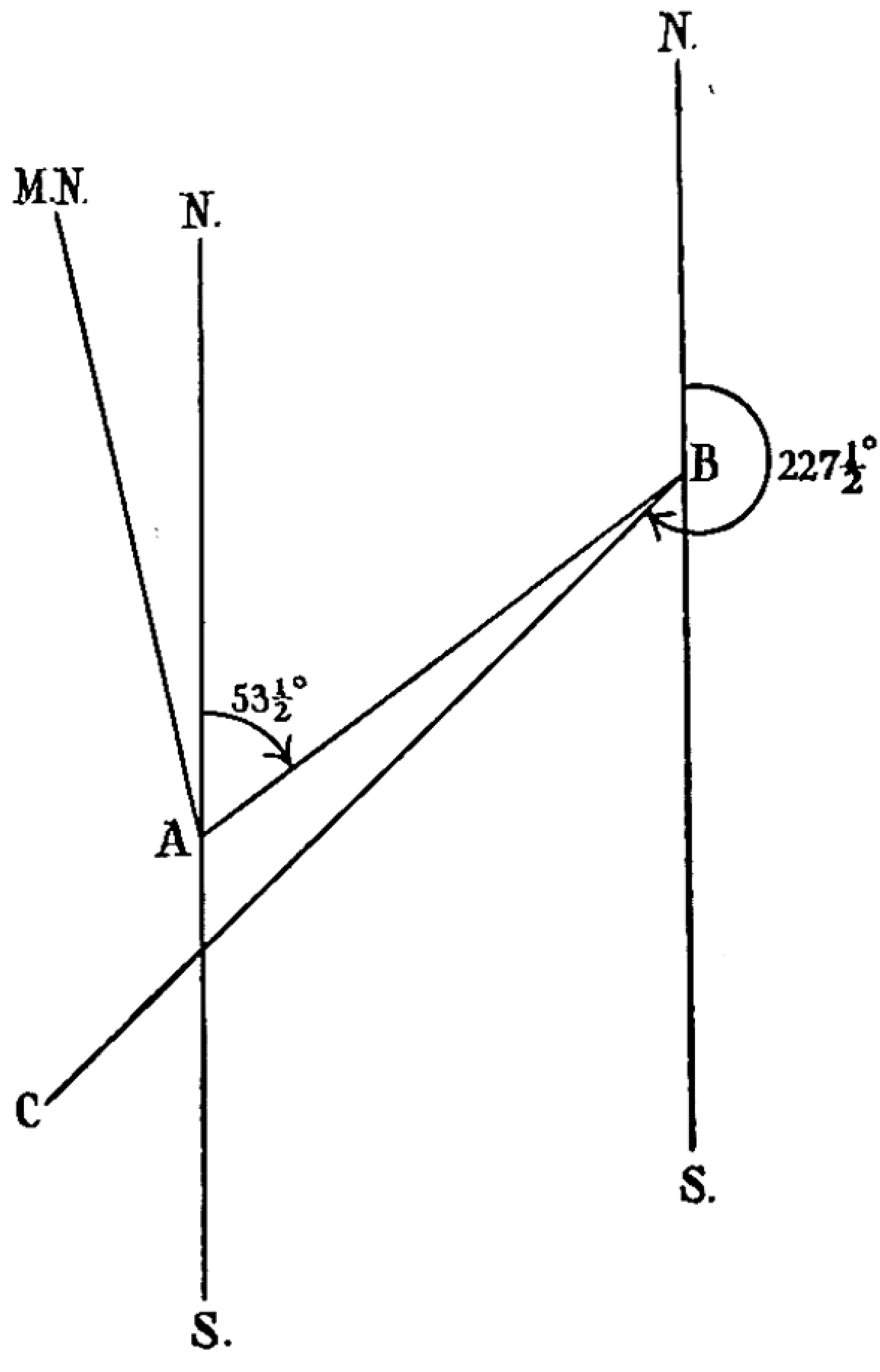
At B draw a line making an angle of $227\frac{1}{2}°$ $(240° - 12\frac{1}{2}°)$ with the south-north line through B, and measure off in this direction 1500 yards from B (2·7 inches). This gives the point C, which is the required destination. By measuring we find that:

(1) Distance from starting-point = ·9 inches = 500 yards.

(2) True bearing of C from A = 211°.

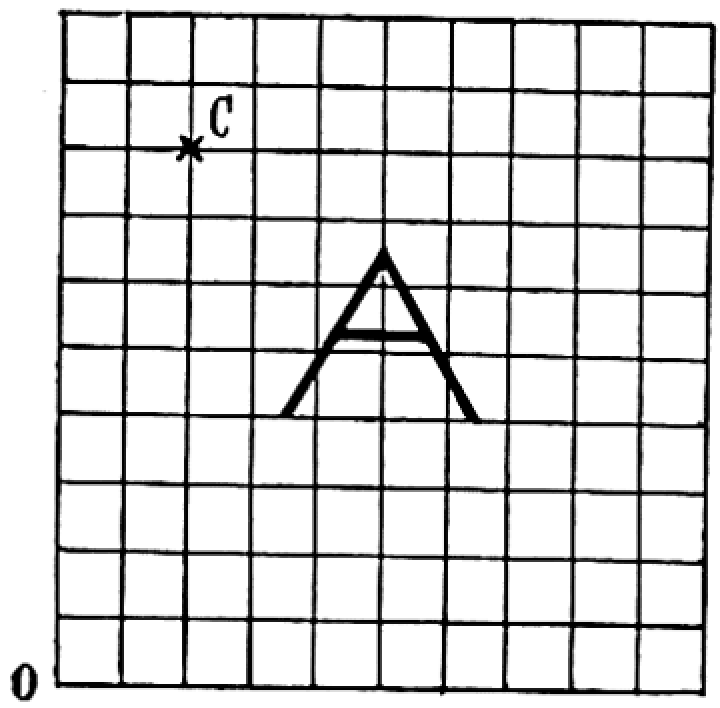
$\therefore$ magnetic bearing of C from A = $211° + 12\frac{1}{2}° = 223\frac{1}{2}°$.

If the exact location of C on the map is required it can be expressed by means of 'co-ordinates.' For this purpose the map or portion of map being used should be divided into squares.



The position of C is fixed with reference to the bottom left-hand corner, O, or 'origin' of the square. Suppose the square divided as in the diagram. Then C is 2 units east of the 'origin' and 8 units north, and is described

as C = (2, 8), 2 and 8 being known as its 'co-ordinates.' The square itself will require some distinguishing mark, such as **A**.



Note. The system of 'squaring' is of special importance in military maps, the small squares of which are divided as in the accompanying diagram. If greater accuracy is required the sides of the square are divided into 100 parts, the location of a position being given as, for example, P = (42, 35). This is known as a 'pin-point' reference.

EXERCISES

1. What are the back bearings of: (*a*) 60°, 275°, 139°; (*b*) 230°, 180°, 305°; (*c*) 12°, 360°, 270°; (*d*) 145°, 56°, 356°?

2. What is the true bearing of the sun in September (*a*) at noon, (*b*) when rising, (*c*) when setting, and (*d*) at 9 A.M.?

3. Plot the following march. From the starting-point go on a magnetic bearing of 8° for 300 yards, then on a magnetic bearing of 105° for 400 yards, and finally for 800 yards on a magnetic bearing of 25°. Find the destination, and give its magnetic bearing and distance from the starting-point. Variation of compass $12\frac{1}{2}$° west.

ANSWERS

1. (*a*) 240°, 95°, 319°; (*b*) 50°, 0° or 360°, 125°; (*c*) 192°, 180°, 90°; (*d*) 325°, 236°, 176°.

2. (*a*) 180°, (*b*) 90°. (*c*) 270°, (*d*) 135°.

3. $39\frac{1}{2}$°; 1200 yards.

CHAPTER VII

SLOPES AND GRADIENTS

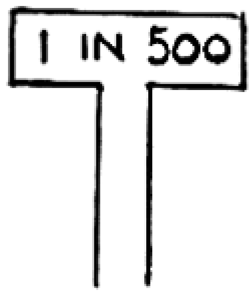
We have seen that the surface relief of a country may assume different forms. A plain, for example, may be practically horizontal. If, however, the surface is inclined to the horizontal plane the ground is said to be on a slope, which may be defined as the inclination of the ground to the horizontal plane. The slope which connects a watercourse and the summit of a hill is rarely a uniformly inclined plane. The degree of inclination continually varies, and causes the ground to assume the forms of concave and convex curved surfaces. From a study of contours it has been learned that, from the higher ground, the inclination is continually increasing on a convex slope and decreasing on a concave slope. In a uniform slope, which is rare, the inclination is constant.

Sometimes it is not sufficient merely to say that a slope is steep or gentle. It may be necessary to describe it in more accurate terms. A study of the contours enables this to be done.

It is usual to measure the inclination of a slope in one of two ways:

1. By a *gradient*—the difference of level which occurs in a given horizontal distance. It is usually expressed as a fraction; *e.g.*, $\frac{1}{10}$ denotes a rise or fall of 1 foot in 10 feet or 1 yard in 10 yards. The gradient of the

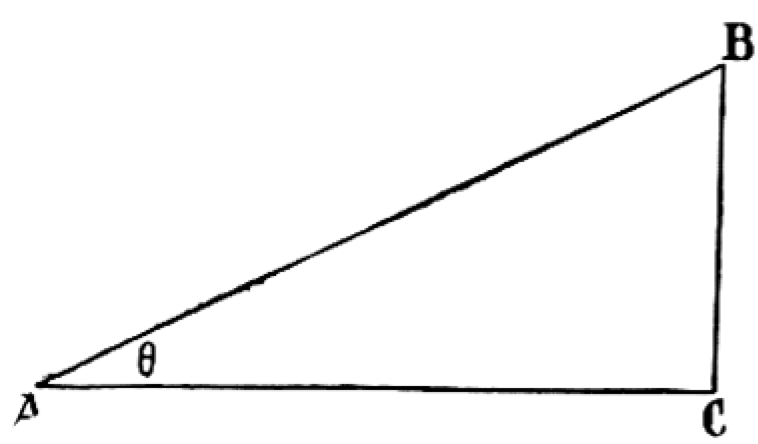
permanent way of a railway is generally shown as in the accompanying diagram, indicating a difference of level of 1 foot in 500 feet or 1 yard in 500 yards.



2. By *degree of slope*—the number of degrees of elevation or depression above or below the horizontal plane—most useful in considering the nature of ground from a tactical point of view.

The two methods are closely connected.

Let A and B represent two points on successive contours and AC the horizontal plane. BC, the difference in height of A and B, will represent the vertical interval (V.I.) of the map and AC the horizontal equivalent (H.E.) of AB. If the length BC be divided by the length AC the ratio $\frac{BC}{AC}$ measures the gradient of AB.



Hence $$\text{gradient} = \frac{\text{V.I.}}{\text{H.E.}}$$

As the vertical interval is strictly the difference in height of adjacent contours, the gradient between two points, each or one of which may not lie on a contour line, is more correctly expressed as

$$\frac{\text{difference in height of points}}{\text{horizontal projection of line joining points}}.$$

If the angle BAC be measured by a protractor then the slope is said to be so many degrees. If θ represents

the degree of slope of AB, the ratio $\frac{BC}{AC}$ is called the tangent of θ, which is usually written

$$\frac{BC}{AC} = \tan \theta.$$

The gradient may thus be considered also as the tangent of the degree of slope. The gradient varies inversely as the stream-line, or line of flow of water. Expressed symbolically,

$$G \propto \frac{1}{\text{stream-line}}.$$

This means that the gradient increases as the stream-line diminishes or becomes shorter—another way of expressing the fact that the closer the contours are the steeper is the slope.

To return to the diagram: let AB be on a slope of 1° and B 1 foot higher than A. By actual experiment it has been found that in order to rise 1 foot above the starting-point at a slope of 1° it is necessary to travel a distance of 19·1 yards, or 57·3 feet. If AB represents a road AC will represent on the map the actual road length. It is the plan of AB, and, since the slope is small, there is little appreciable difference between the lengths of AB and AC, so that AC may also be taken to represent 57·3 feet. It is also true that for the more gentle slopes the horizontal equivalents are approximately proportional to the angle of slope.

Hence a slope of 1° is equivalent to a gradient of 1 in 57·3;
„ 2° is equivalent to a gradient of 1 in 28·6;

Hence a slope of $3°$ is equivalent to a gradient of 1 in 19·1;
" $5°$ is equivalent to a gradient of 1 in 11·4;
" $10°$ is equivalent to a gradient of 1 in 5·7.

This approximation for small angles may be expressed in the form of an equation thus:

$$\frac{\text{V.I.}}{\text{H.E.}} = \frac{\text{D}}{57{\cdot}3}$$

or (by transposition) $\text{H.E.} = 57{\cdot}3 \times \dfrac{\text{V.I.}}{\text{D}}$

where H.E. = horizontal equivalent,
V.I. = vertical interval,
D. = degree of slope.

Thus the length of the horizontal equivalent corresponding to a given degree of slope may be calculated for any map whose vertical interval is known.

Note. Since $\dfrac{1}{57{\cdot}3}$ is the natural tangent of $1°$ it is only necessary, in expressing any degree of slope as a gradient, to refer to a table of natural tangents. For small angles up to about $10°$ the gradient may be obtained approximately by dividing the number of degrees of slope by the reciprocal of the tangent (the co-tangent) of $1°$. This does not apply to large angles, as error rapidly increases with increase of angle.

Summary

(*a*) To convert a degree of slope to the corresponding gradient divide the number of degrees by 57·3.

E.g., $2\frac{1}{2}°$ slope is equivalent to gradient $\frac{2\frac{1}{2}}{57\cdot3}$

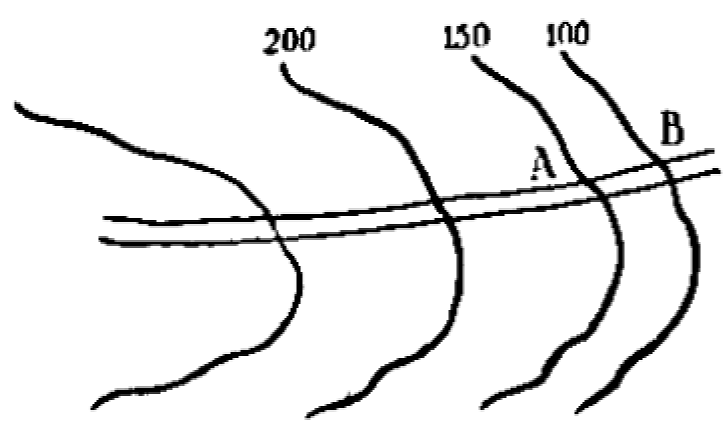
$$= \frac{1}{22\cdot9}.$$

(*b*) To convert a gradient to the corresponding degree of slope multiply the gradient by 57·3.

E.g., gradient $\frac{1}{12}$ is equivalent to $\frac{1}{12} \times \frac{57\cdot3}{1}$ degrees of slope $= 4\cdot8°$.

Gradient of Roads

From a practical point of view it is only necessary to consider the effect of a gradient upon marching or transport. Consequently it is sufficient to find the gradient of the steepest part of the road.



Gradient from Map. The portion of road between A and B is the steepest, since the contours are closest between these points. The vertical interval is 50 feet, and the horizontal equivalent, the distance between contours, can be measured off the scale of yards on the map. Suppose it measures 400 yards. Then gradient

$$= \frac{\text{V.I.}}{\text{H.E.}}$$

$$= \frac{50}{400 \times 3}$$

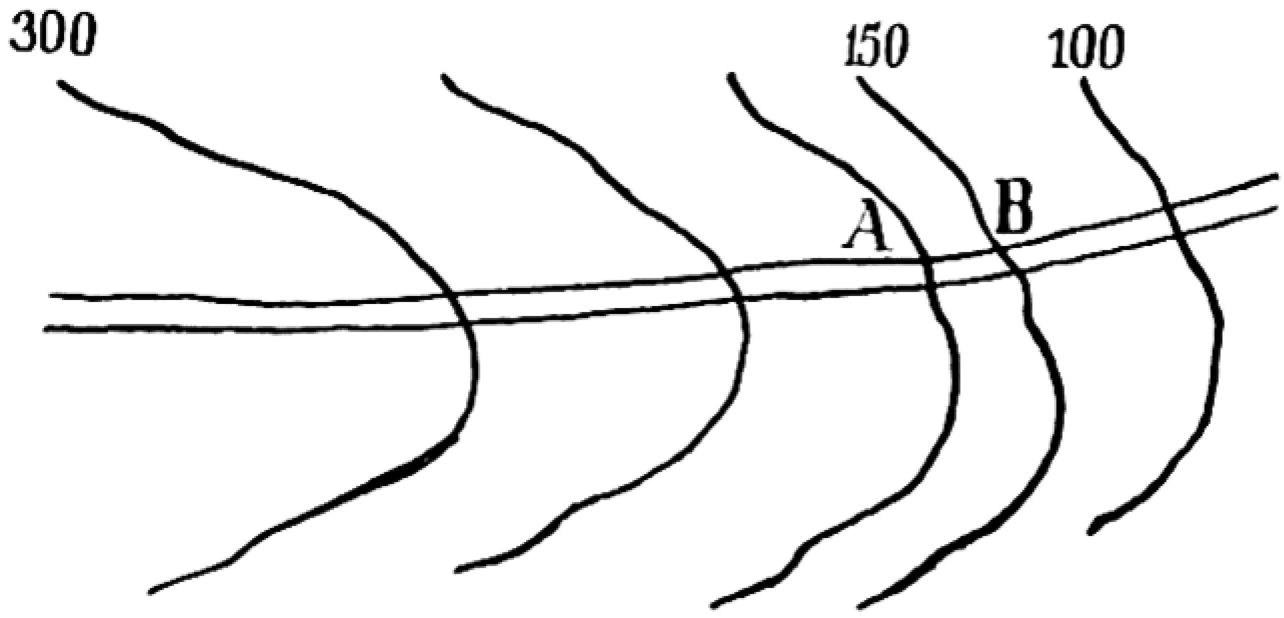
$$= \frac{1}{24}.$$

$$\therefore \text{degree of slope} = \frac{1}{24} \times \frac{57\cdot3}{1}$$

$$= 2\cdot4° \text{ (approx.)}.$$

This is a fairly steep gradient. The difficulty in ascending a hill whose slope is $2\frac{1}{2}°$ to $3°$ can be obviated by 'tacking'—*i.e.*, zigzagging up the hill—which reduces the slope at the expense of distance and time. Of course, in ascending a hill by walking there is little reduction of speed from the ordinary rate possible on level ground, so that in general, even with some encumbrance, a steep short cut is preferable to the sacrifice of distance and time in going round. On the other hand, in the case of wheeled transport, it has been found that on a gradient of 1 in 24, or roughly $2\frac{1}{2}°$ slope, horses can drag only half as great a load as on the level.

Example. Find the steepest road gradient in the following diagram (scale of map $\frac{1}{20,000}$, V.I. 50 feet):



In the absence of a scale of yards the R.F. is a necessary part of the data.

The steepest gradient is between A and B. By measurement AB is found to be $\frac{3}{8}$ inch.

Now 1 inch on the map represents 20,000 inches on the ground.

$\therefore \frac{3}{8}$ inch on the map represents 7500 inches on the ground—*i.e.*, 625 feet.

$$\therefore \text{gradient} = \frac{\text{V.I.}}{\text{H.E.}}$$

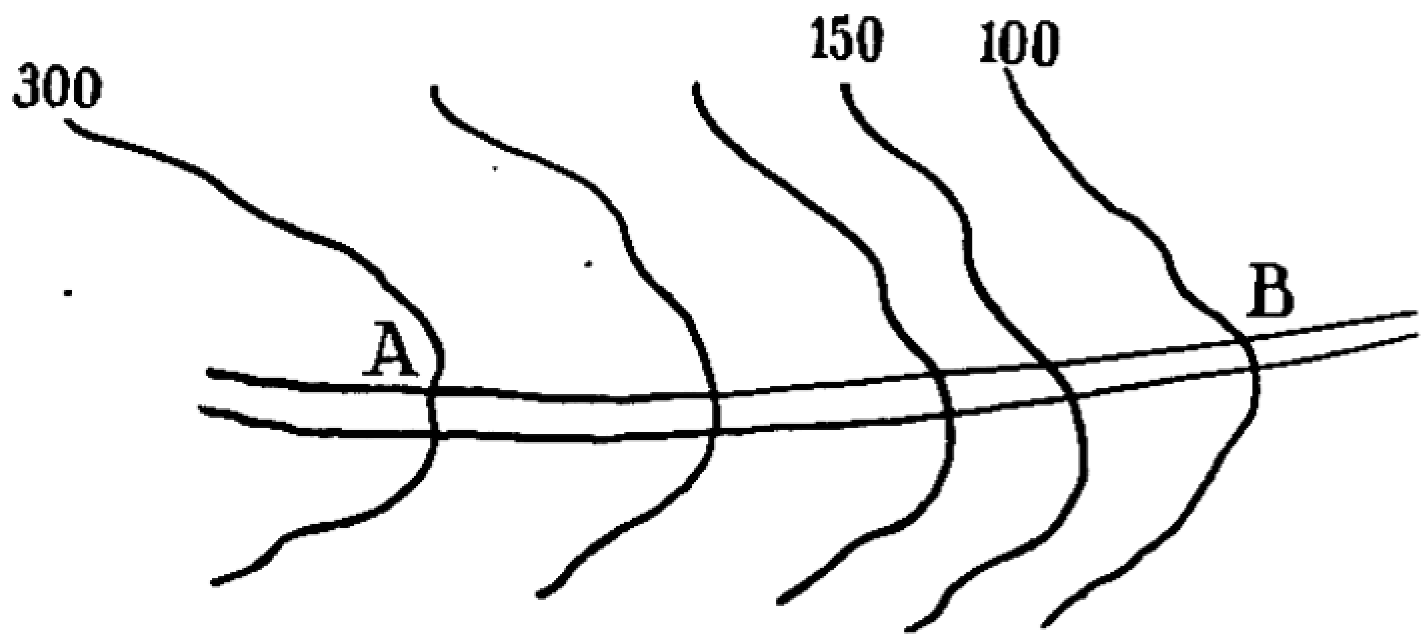
$$= \frac{50}{625}$$

$$= \frac{1}{12{\cdot}5}.$$

$$\therefore \text{degree of slope} = \frac{57{\cdot}3}{12{\cdot}5}$$

$$= 4{\cdot}5^\circ \text{ (approx.)}.$$

Average Gradient. The method of finding the average gradient of the road between A and B is identical with



that of finding the steepest gradient, except that the V.I., instead of being 50 feet, will be the difference in height of A and B, in this case $50 \times 4 = 200$ feet. Suppose horizontal distance AB measures 1·8 inches, which is equivalent to 3000 feet at the scale of $\frac{1}{20{,}000}$.

$$\text{Then gradient} = \frac{200}{3000}$$

$$= \frac{1}{15}.$$

$$\therefore \text{ degree of slope} = \frac{57 \cdot 3}{15}$$

$$= 3 \cdot 8^\circ \text{ (approx.)}.$$

Scale of Slopes or Horizontal Equivalents. The scale of a map being given and also the vertical interval, it is required to find the horizontal equivalent, or distance in yards at which a given difference of height will occur at a given degree of slope. The difference of height chosen is the contour interval of the map upon which the scale is to be used. The required distance is found from a scale of slopes—a scale, that is to say, on which are marked off the distances in yards for different degrees of slopes.

Suppose the scale of the map is $\frac{1}{10,000}$ and the vertical interval 25 feet. 1° slope represents a gradient of $\frac{1}{57 \cdot 3}$. Expressing this gradient as $\frac{\text{V.I.}}{\text{H.E.}}$:

$$1^\circ \text{ slope represents a gradient of } \frac{25}{57 \cdot 3 \times 25}.$$

This means that with V.I. 25 feet the horizontal distance between adjacent contours corresponding to 1° slope is $57 \cdot 3 \times 25 = 1432 \cdot 5$ feet. Similarly for 3° slope the H.E. is $19 \cdot 1 \times 25 = 477 \cdot 5$ feet, for 5° slope $286 \cdot 5$ feet, and so on. It is necessary then to find what

length represents 1432·5 feet on a scale of which the R.F. is $\frac{1}{10,000}$.

Method. 10,000 inches on the ground are represented by 1 inch on the map.

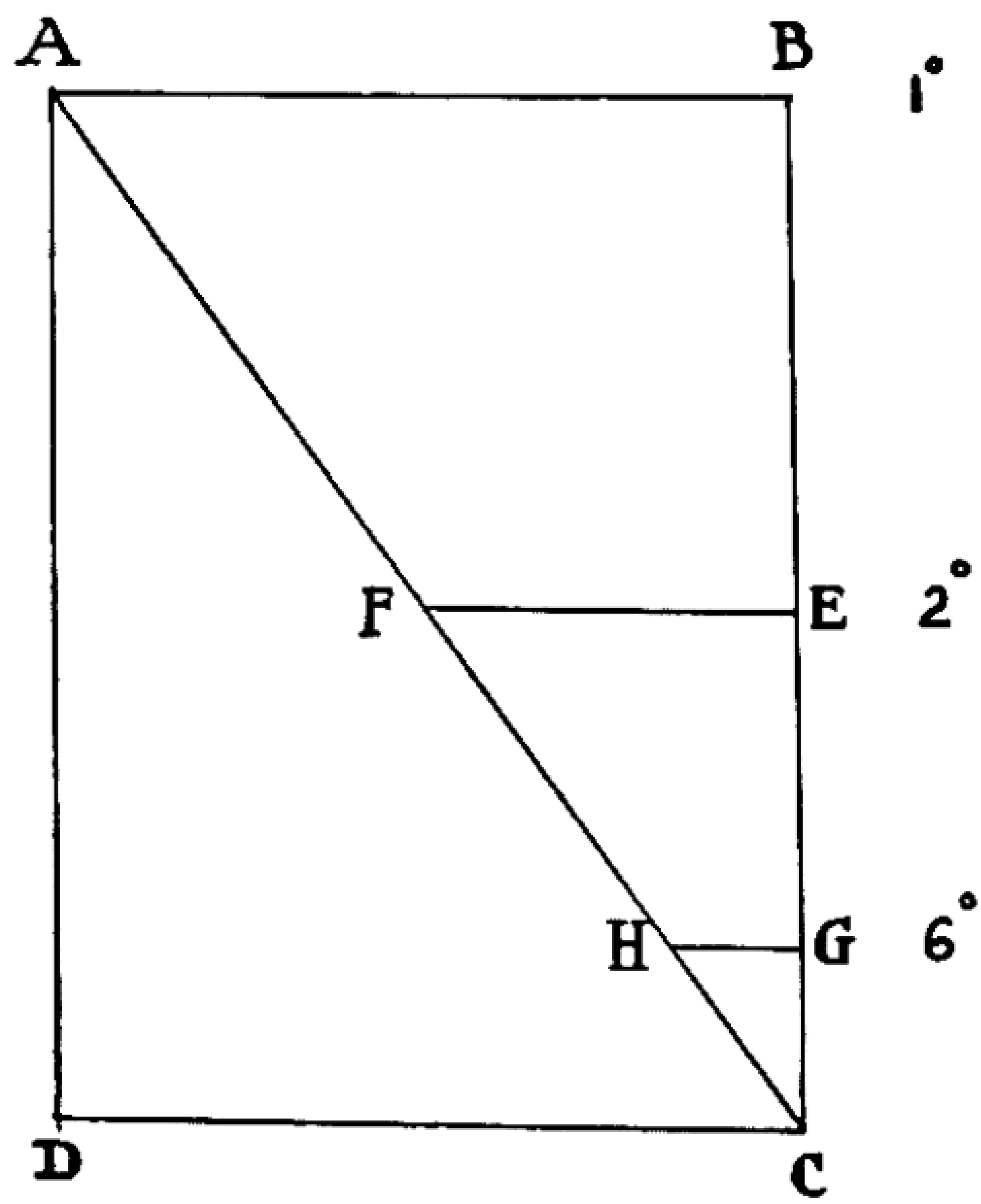
I.e., $\frac{10,000}{12}$ feet on the ground are represented by 1 inch on the map.

$\therefore$ 1 foot on the ground is represented by $\frac{12}{10,000}$ inch on the map.

$\therefore$ 1432·5 feet on the ground are represented by $\frac{12}{10,000} \times \frac{1432\cdot5}{1}$ inches on the map.

$= 1\cdot719$ inches on the map.

Draw a line, AB, 1·72 inches long. This length represents the horizontal distance between adjacent contours for 1° slope. From A and B set off perpendiculars of any equal length, AD and BC respectively. Join DC and AC.



Suppose the horizontal distance corresponding to 2° slope is required. Bisect BC in E. Draw EF parallel

to BA. By geometry it follows that since triangles ABC and FEC are similar, FE will bear the same ratio to AB that CE bears to CB. Therefore, as CE $= \frac{1}{2}$CB, FE $= \frac{1}{2}$AB.

Thus FE represents the distance between contours for 2° slope. Similarly the distance for any degree of slope can be found by dividing BC into as many equal parts as there are degrees of slope.

Required Distance for 6° Slope

Mark a point G along CB such that CG $= \frac{1}{6}$CB.
Draw GH parallel to BA.
Then GH $= \frac{1}{6}$AB.

By applying any distance between adjacent contours to the above scale of slopes the steepness of the ground at any point can be ascertained.

EXERCISES

1. Express the following gradients as degrees of slope: $\frac{1}{9}$, $\frac{1}{15}$, $\frac{1}{30}$, $\frac{1}{45}$, $\frac{1}{90}$.
2. Express the following degrees of slope as gradients: 2°, $2\frac{1}{2}$°, 3°, 5°, $7\frac{1}{2}$°, 10°.
3. A road rises $4\frac{1}{2}$ feet in 100 yards. Express this as a gradient and in degrees of slope.
4. Construct a scale of slopes for a map drawn to a scale of $\frac{1}{5000}$, V.I. 20 feet.
5. Show the horizontal equivalents for 1°, 2°, 3°, 5°, 6°, and 10° for a map whose scale is 6 inches to 1 mile, V.I. 50 feet.

ANSWERS

1. 6·4° (approx.), 3·8° (approx.), 1·9° (approx.), 1·3° (approx.), ·6° (approx.).

2. $\frac{1}{28\cdot 6}$ (approx.), $\frac{1}{22\cdot 9}$ (approx.), $\frac{1}{19\cdot 1}$ (approx.), $\frac{1}{11\cdot 4}$ (approx.), $\frac{1}{7\cdot 6}$ (approx.), $\frac{1}{5\cdot 7}$ (approx.).

3. $\frac{1}{67}$ (approx.), $\cdot 85^\circ$ (approx.).

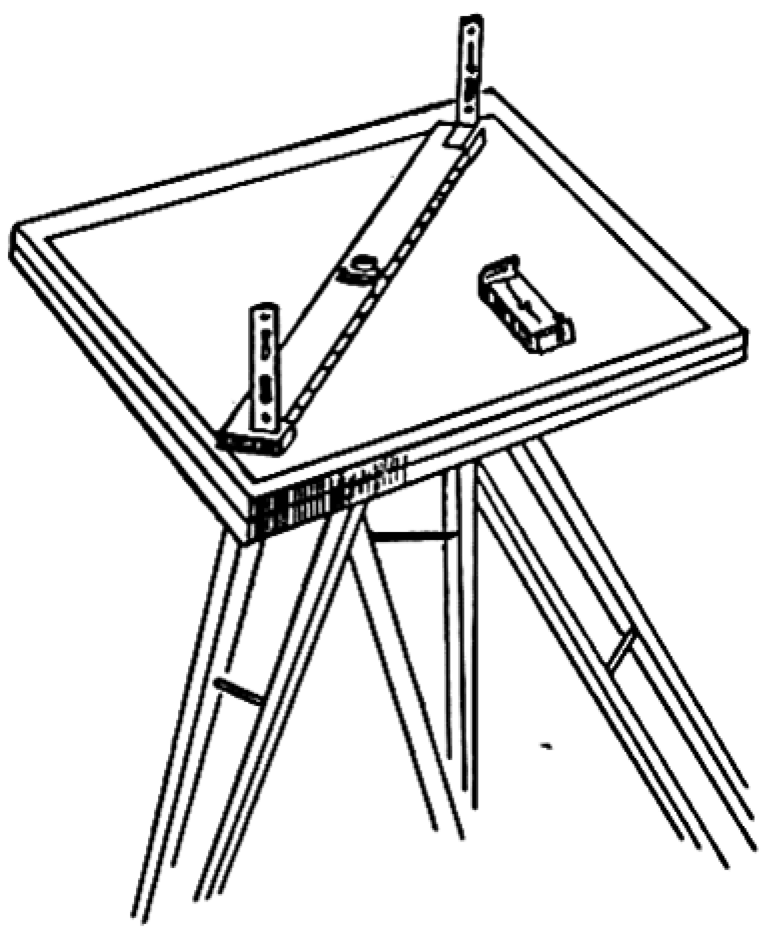
4. 2·75 inches (approx.) for 1° slope.

5. 3·25 inches (approx.) for 1° slope; 1·63 inches (approx.) for 2° slope; 1·1 inches (approx.) for 3° slope; ·65 inches (approx.) for 5° slope; ·54 inches (approx.) for 6° slope; ·33 inches (approx.) for 10° slope.

CHAPTER VIII

THE PLANE-TABLE

BEFORE a map can be made the actual ground has to be surveyed. This is done by dividing it up into a network of triangles by the measurement of angles, thus fixing a series of stations. By means of smaller triangles further detail can then be inserted by the use of a plane-table. This is known as *graphic triangulation*.



At first the plane-table was not looked upon as a very accurate means of measurement, but as the methods of using it were made more accurate it began to be more largely employed. In the construction of maps for the Great War it played a very important part. By its aid it is possible to make a complete and accurate map without any previous triangulation.

In its simplest form the plane-table consists of a portable drawing board mounted on a rigid tripod stand and fitted with a separate sighting ruler called an *alidade*. A screw on the tripod enables the board to be fixed or revolved as necessary.

A sheet of drawing paper, somewhat larger than the board, is mounted on it. It is preferable to damp the

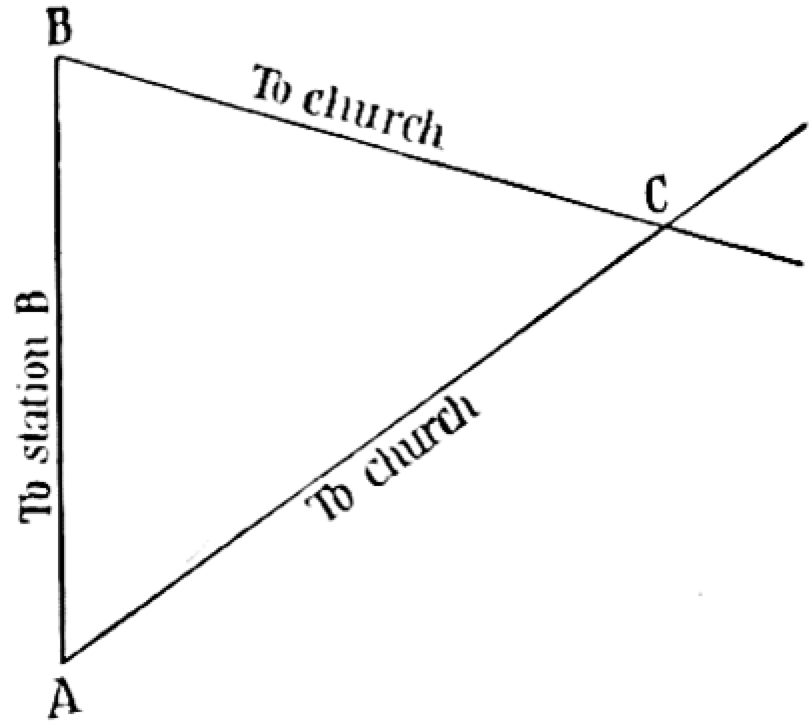
paper so that it may stretch and then contract on the board after drying, thus presenting a tight and even surface. Sometimes a sheet of calico or linen is soaked and stretched on the plane-table, the edges being pasted on the under-side. This substitute for drawing paper is used when very great accuracy is required.

Alidade. This is a heavy boxwood ruler with bevelled edges and marked with various scales. There is a hinged metal sight at either end. The back-sight has a narrow vertical slit in it, the fore-sight a wider slit in which a vertical thin wire or hair is fixed as a sighting vane. The line of sight is parallel to the side of the ruler. When objects at a distance are being sighted, or when the plane-table is the only instrument being used, a telescope with cross wires in the eyepiece may take the place of the sights.

Box or Trough Compass. This also is necessary for plane-tabling. It is a magnetic needle about five inches long fitted into a metal trough, the whole being enclosed in an oblong wooden box with parallel sides. At each end of the box short arcs are graduated to show ten or twenty degrees.

Method of Graphic Triangulation. A base must be chosen and measured. From the ends of the base the chief features to be mapped must be visible. No numerical measurement of angles is necessary, as the drawing is done on the spot. At A, one end of the base, the tripod is set up, and the board with paper attached, after being made horizontal by means of a spirit-level, is tightly secured. A point on the paper is marked to represent station A. The sight ruler is then placed against a pin inserted in A, and it is turned until

station B, at the other end of the base, is sighted. The line AB is then drawn. An outstanding object C, say a church, is then sighted by turning the ruler round the pin at A and drawing a line along the edge of the ruler toward the church.



This process is gone through for all principal features in sight from A. While this is being done the tripod must not be moved nor the board unclamped. The table is then carried to station B and set up. It is important to notice that, before any readings are taken at B, the first station, A, must be sighted and the board revolved till the line BA is lying exactly along the edge of the ruler—*i.e.*, the ruler must point straight back to A. The object C is then sighted again and a line drawn toward it and marked 'to church.' The point of intersection of the two lines drawn toward the church from A and B fixes the position of the church on the map which is being drawn. The positions of other objects that were sighted at A are found in the same way.

If any points were invisible from either of stations A and B it would be necessary to take a third station from which they could be seen. In any case, a third line would provide a check on the accuracy of the previous observations. This graphical method is largely used for work in the field.

Practical Hints

1. In using a plane-table see that the clamping screw under the table is taut. If a telescopic or folding tripod be used leg screws on it must be tightened up.

2. The legs must be set firmly on the ground and the board kept horizontal and at a convenient height.

3. If distant objects are being identified field-glasses are useful.

4. To ensure accurate work two pencils are essential—one for fine construction lines, the other for completing details.

5. Make sure that the whole of the sketch is included within the limits of the paper.

CHAPTER IX

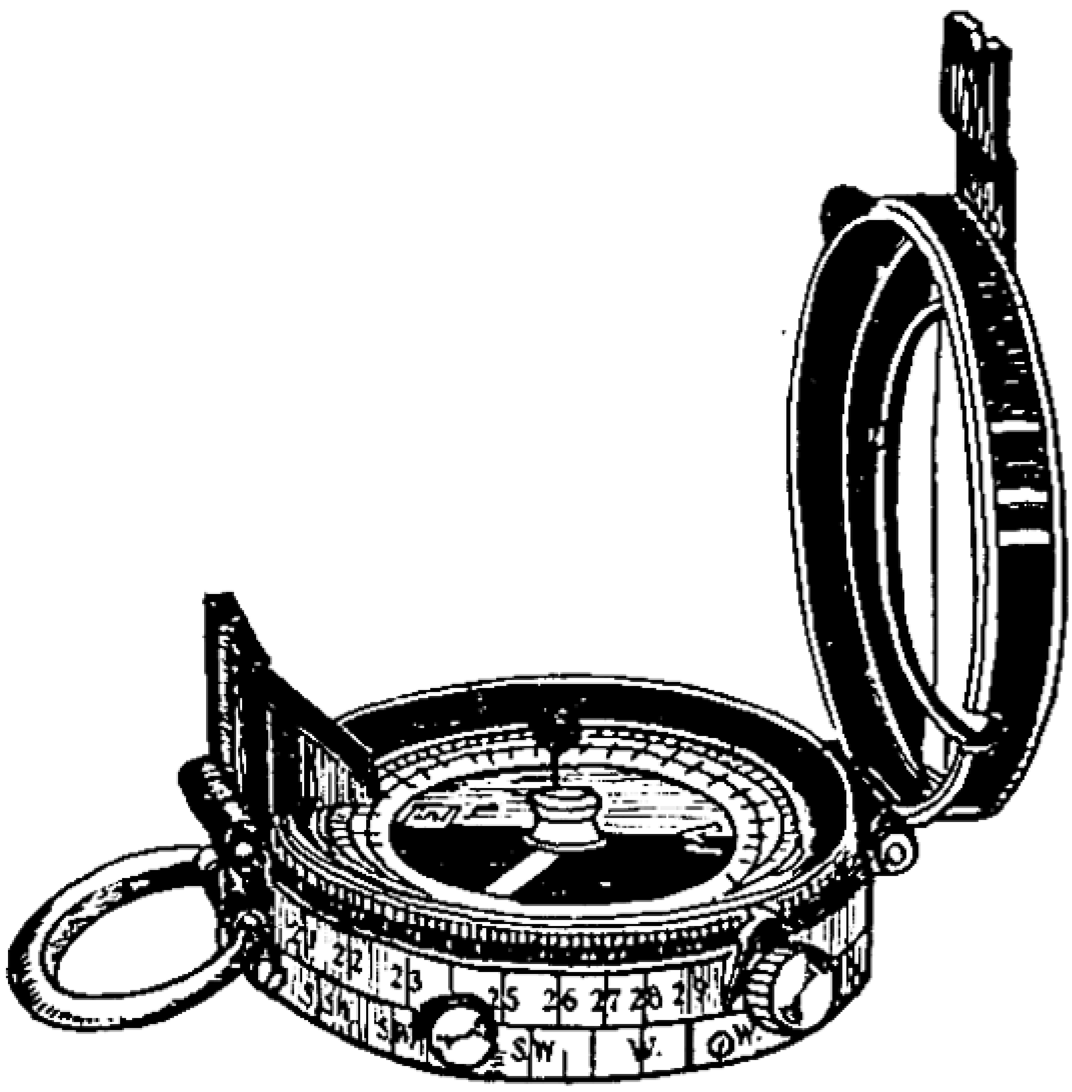
THE PRISMATIC COMPASS

WHERE a regular survey of a country has to be made and the greatest accuracy is necessary the most exact instruments, sometimes heavy and elaborate, are essential. But it often happens that a rapid survey has to be undertaken in a limited time and when only easily portable instruments are available. In such circumstances simpler methods are sufficient. Of the instruments that could be used the prismatic compass, although not so accurate as the plane-table nor so suitable in open country, is particularly well adapted. Fairly trustworthy results can be obtained provided that the compass needle is not unduly influenced by the presence of iron in its neighbourhood.

Description. The prismatic compass is a combination of a magnetic needle attached to a dial and a prism. The dial, which may be of paper, celluloid, or pearl, is balanced on a pivot and is divided into 360 degrees, the magnetic needle being immediately under the 360 point. The dial is contained in a circular metal case, round the margin of which there is a brass ring divided at intervals of five degrees and also marked with the points of the compass. The case is fitted with a glass lid which can be revolved. The outside of this movable window frame is toothed, and can be locked or fixed by means of a pointed catch worked by a milled screw on the side of the case. A metal lid hinged to the case is provided to cover the compass. Into this

is let a glass window with a lubber line or direction line, at each end of which are luminous patches for night marching.

The magnetic needle on the dial may be luminous, and there may be a luminous patch on the movable glass lid immediately above a metal indicator, which is used as a setting mark.



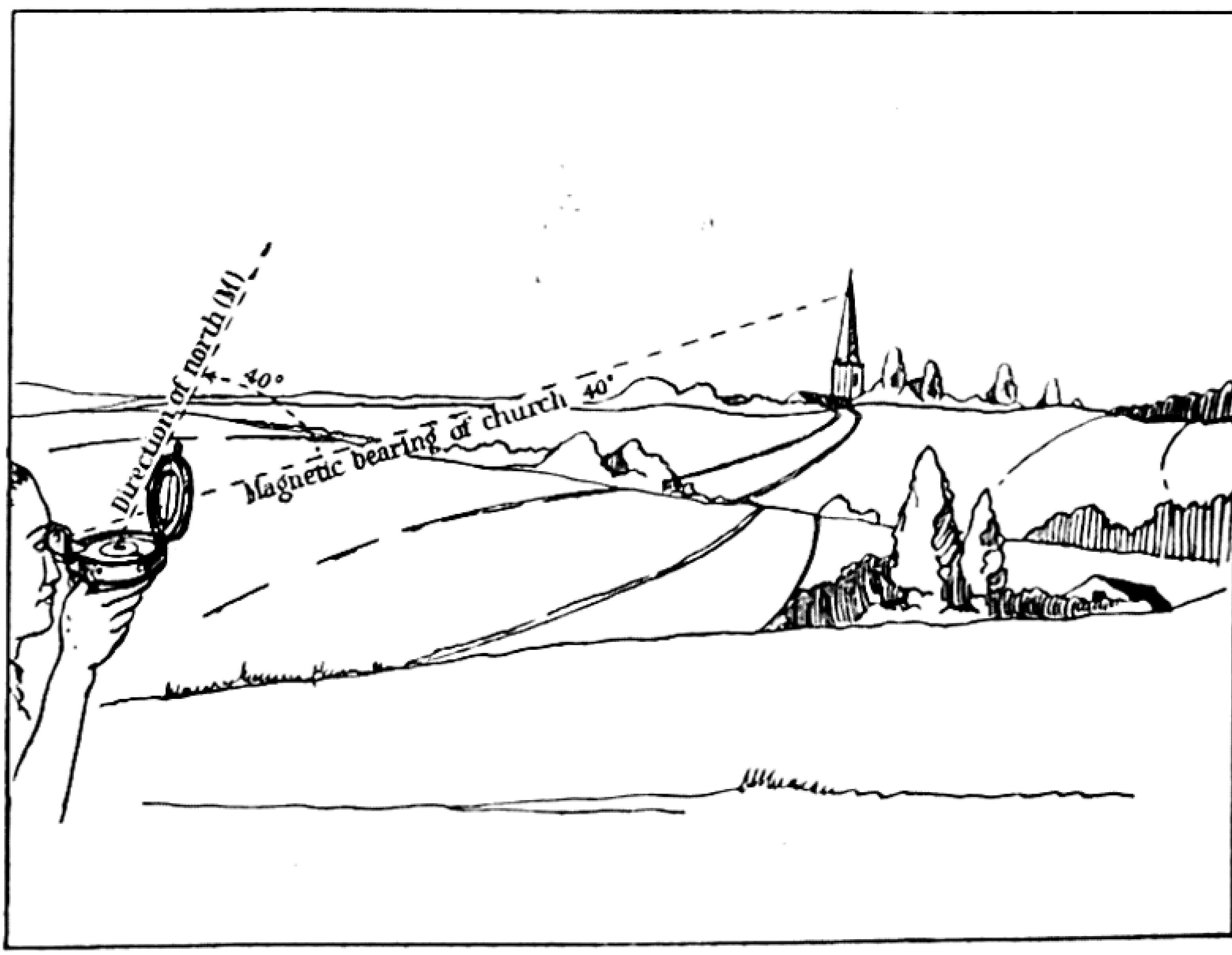
Opposite the hinge of the metal lid a prism is fitted which enables the person taking a bearing to read by reflection the degrees marked on the graduated dial, and at the same time, through a slit on the prism cover, permits the lubber line and the observed object to be brought into alignment. A check-stud near the prism clamps the dial and prevents oscillation when the compass is not in use. It also serves to check the motion of the dial if it revolves too quickly when being used. The prism should be moved up and down in its socket until the figures are in correct focus. A metal projection

protects the prism when the compass is closed. The dial is clamped when a bearing is being taken.

Graduations on the Dial. There are two sets of figures, an outer and an inner. The outer set is graduated to read single degrees, the figures of which are in inverse order and intended to be read through the prism. The numbering starts at south and is clockwise.

The inner set of figures, graduated at intervals of five degrees, is used for direct reading (without the prism), for night marching, or for setting a map. In most cases the single-degree divisions of the outer scale can be utilized in conjunction with the inner set of graduations.

To take a Bearing. Raise the lid until it is at right angles to the surface of the compass, move the prism



into position for use, and unclamp the dial. Looking through the slit in the prism cover, align the sighting

line on to the object, if necessary checking the oscillation of the dial by the check-stud. Then read the bearing through the prism under the sighting line or the index line inside the compass case, which is in prolongation of the sighting line.

To use without the Prism. Place the compass on the hand or on any flat surface. Open the lid out to the full extent. Align the sighting line on the object, and when the dial comes to rest read the degrees on the inner scale under the index line. This reading gives the magnetic bearing.

To test the Compass. Many compasses have a small individual error which should be known in each case in order that allowance may be made for it. Select some position on the map to which you can proceed. This should be some very definite point, such as the junction of two hedges, or a road and a hedge, and not near any metal work. Select also some well-defined distant object the bearing of which it is easy to take. Measure on the map the magnetic bearing of the distant object from the first selected position. Then take a series of compass readings on the ground. The average deviation of the compass bearing from the map bearing is the compass error, and should be noted in some convenient place on the compass, commonly inside the rubber ring on the case.

Example. The bearing to a certain object measured from the map is 158°. Compass readings give $157\frac{1}{2}°$, 158°, 157°, 158°, $156\frac{1}{2}°$, 157°.

∴ average reading is 157° 20′.

∴ average error of the compass is 40′ minus.

Night Marching by Compass. Revolve the movable glass lid until the metal indicator is at the required

bearing on the outside of the case—*e.g.*, for a bearing of 150° it will be opposite the number 15. Clamp the lid to prevent the glass window moving. Unclamp the dial and let it swing freely. Then revolve the compass until the magnetic north-seeking arrow and the luminous patch on the movable lid are in line. The two luminous patches at either end of the sighting line will then be pointing in the direction of the line of march. Care should be taken that the lubber line on the glass window coincides with the metal indicator, as the glass sometimes becomes loose.

To take a Range by Compass. Take a bearing by compass to the object the range of which is required. Then place a convenient base as nearly as possible at right angles to the distant object and take another bearing to the object. The difference between the two bearings is called the *apex angle*. Therefore, since the apex angle and base are known, it is only necessary to apply the formula

$$\text{D (apex angle)} \times \text{H.E. (range)} = \text{V.I. (base)} \times 57{\cdot}3.$$

$$\therefore \text{range} = \frac{\text{base} \times 57{\cdot}3}{\text{apex angle}}.$$

For convenience substitute 60 for 57·3. Assuming, for example, a range of 5000 yards and a hundred-yard base, we see that

$$5000 = \frac{100 \times 60}{\text{apex angle}}$$

$$= \frac{1000 \times 6}{\text{apex angle}}.$$

$$\therefore 5 = \frac{6}{\text{apex angle}}.$$

Thus, for a hundred-yard base

$$\frac{6}{\text{apex angle}} = \text{thousands of yards in the range.}$$

Similarly, for a 200-yard base

$$\frac{12}{\text{apex angle}} = \text{thousands of yards in the range.}$$

It is obvious that a suitable numerator can be worked out for any base—the longer the base the more correct the result.

Example. Base = 300 yards.

Bearing of object from one end = 150°.

Bearing of object from other end = 146°.

$\therefore$ apex angle = 4°.

Numerator for base of 300 yards = 18.

$$\frac{18}{4} = 4\tfrac{1}{2} \text{ thousands of yards.}$$

$\therefore$ range = 4500 yards.

CHAPTER X

VISIBILITY

A PROBLEM of some importance which occurs frequently in map-work is to determine from the map the mutual visibility of points, whether a certain point on the ground is visible from another and *vice versa*, or to what extent observation is possible from any given point. A study of this problem of intervisibility, which investigates the conditions resulting from the changes of slope between two points, enables one to fix the points from which good views of any particular portion of country can be obtained—where, for example, a road or a river will be obscured from view and where it will reappear, and other important details connected with the configuration of the ground.

In considering the ground between successive contours one must not assume that it is perfectly even. Irregularities occur which are not shown owing to the relatively large vertical interval of the map. Woods and large buildings will be indicated, but minor features, such as trees and hedges, which may be important factors, are apt to be omitted in a small-scale map, thus interfering with the most careful calculations.

To determine whether one point is or is not visible from another various methods are employed, the most usual being:

1. Inspection.
2. Profile- or section-drawing.
3. Rise or fall of line of sight.

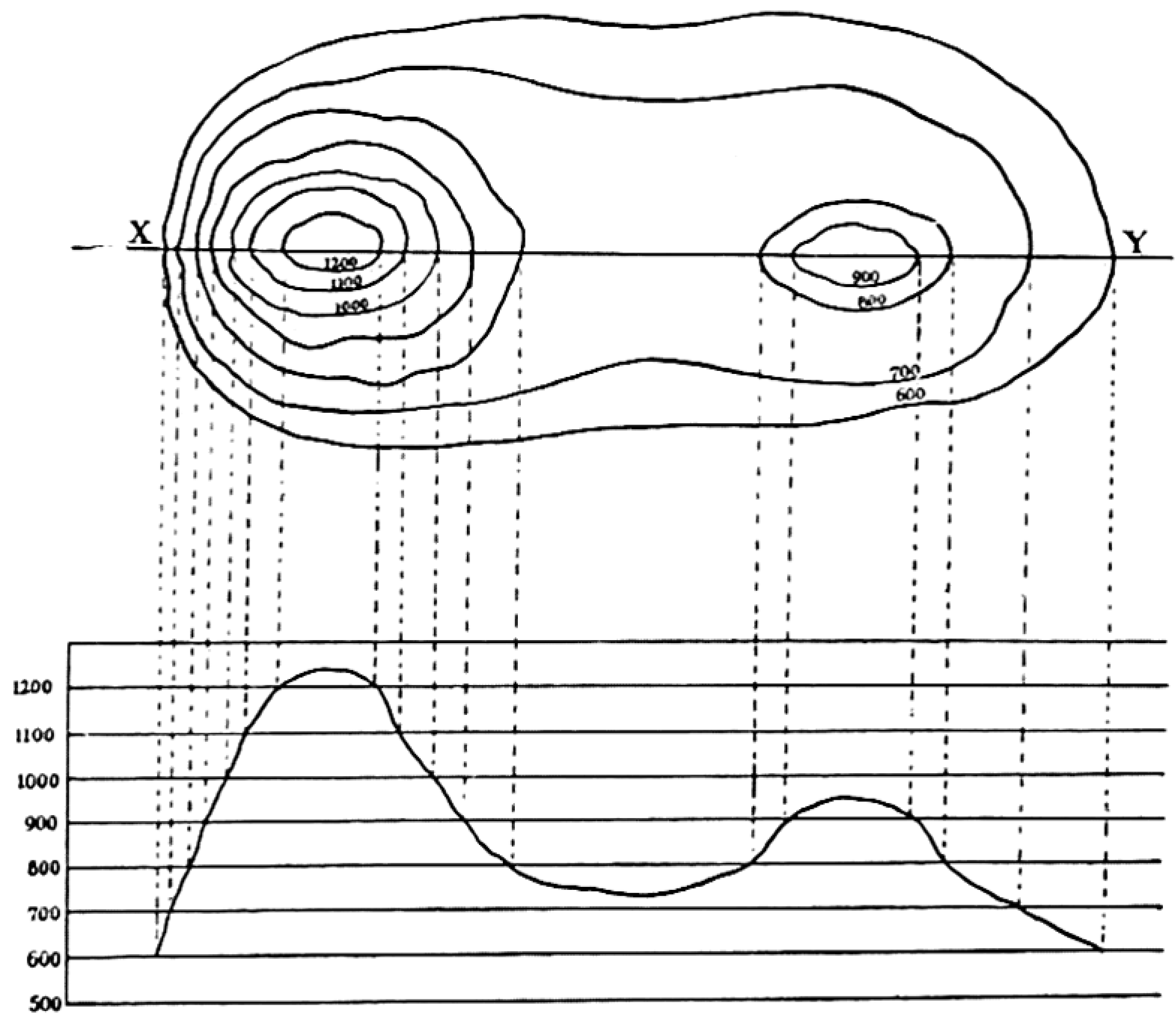
4. Comparison of gradients.
5. Comparison of angles of sight.

1. **Inspection.** Sometimes visibility problems can be satisfactorily solved by a visual examination of the contours. Study the contours intervening between two points under consideration and form a mental picture of the configuration of the ground between. If the general slope is concave the points are mutually visible, but if the slope is on the whole convex they are not. In an undulating slope it is difficult to say with any degree of certainty whether there is mutual visibility. The solution of such problems by inspection is largely a matter of practice. Care must be taken to determine whether under-features will rise high enough to become obstructive.

2. **Profile- or Section-drawing.** In doubtful cases, where inspection is not a reliable guide, it is necessary to draw a profile, or section, of the ground. This is a curving line along which any vertical plane cuts the ground. To depict the form of the surface along any given line, therefore, the ground is imagined to be cut by a vertical plane. Its profile can then be constructed geometrically either on the map itself or, preferably, on a separate sheet of paper. Suppose a section is required to be drawn along the line XY (diagram).

Place the straight edge of a piece of paper along the line joining the two points and mark where each contour cuts this edge. Number sufficiently to avoid the possibility of misreading any contours. Several inches below the edge of the paper draw a series of horizontal lines at equal distances apart representing the vertical intervals of the map, the lines being numbered from lowest to highest with the numbers respectively of the

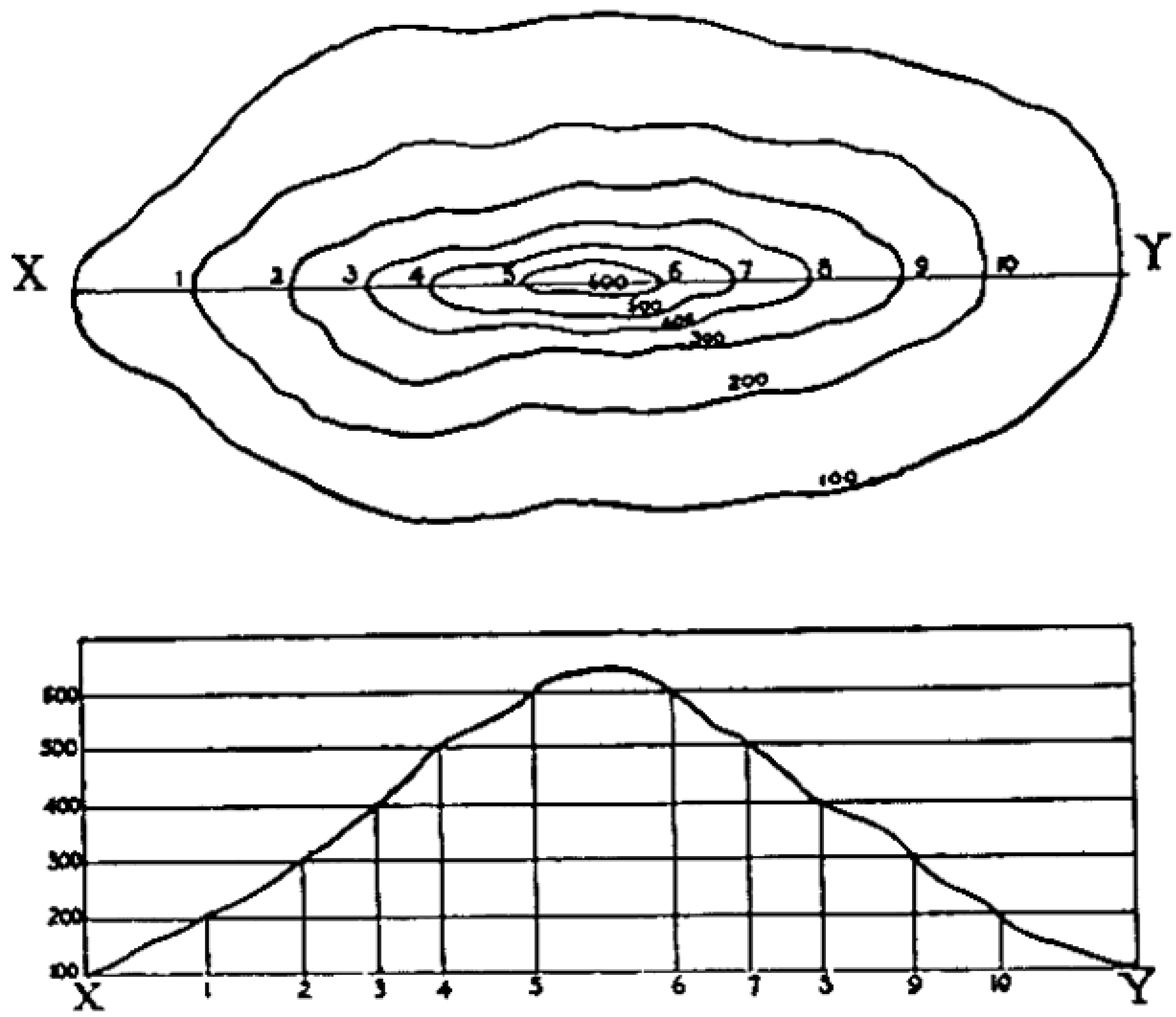
lowest and highest contours involved. From the contour marks on the edge of the paper drop perpendiculars on to the corresponding contour lines. The points at which these perpendiculars cut the horizontal lines indicate the positions of the contours on the section.



Join these points by a freehand curve. This gives the profile required. Note that two similarly high contours with no higher one intervening may indicate the summit of a hill or ridge, in which case the natural curve should be continued, representing a crest slightly above the highest contour marked. In the case of two similarly low contours with no lower one intervening an additional drop between these two contours must be allowed for.

The straight line joining X and Y is called the line of sight. If it clears all intervening ground X and Y are mutually visible; otherwise they are not.

If the section be drawn on a separate sheet of paper the process consists simply of setting off distances and plotting points, and is similar to the construction of



any graph. The line corresponding to the lowest contour on the line of section is taken as the axis from which distances and heights are measured and plotted. Draw a horizontal line equal in length to XY, and transfer to it the distances corresponding to the division of XY by the contours. From each of the points marked raise perpendiculars proportional to their contour heights. The curved line formed by joining the tops of the perpendiculars will give an approximate representation of the profile of the country along the line XY.

It is customary, at least in the smaller-scaled maps,

to exaggerate the vertical interval in a section, as slopes would appear so small that the relative changes would scarcely be noticeable, and consequently the section would be of very little use. For example, on a '1-inch' map a 100-feet vertical interval would be represented by $\frac{1}{53}$ inch. It is necessary therefore to exaggerate the vertical interval six or seven times, bringing the distance between the horizontal lines to about $\frac{1}{8}$ inch. This is found to give a very useful and satisfactory section. The scale for the vertical interval may be made as many times larger than the horizontal scale as desired. If, however, a true section is required the distances, before being set off along the horizontal, will have to be increased in the same proportion as the vertical interval. It is advisable to state the multiplying factor; otherwise the section is apt to confuse. Squared paper may be conveniently used for section-drawing, one or more divisions representing the vertical interval.

Although many minor undulations not indicated by the large vertical intervals of the contours may occur to impair the reliability of sections, yet, on the whole, sections are extremely important in affording a graphic picture of comparative slopes and gradients, particularly of roads. Their importance is recognized by their frequent inclusion in motoring and cycling road books.

3. **Rise or Fall of Line of Sight.** Suppose X is higher than Y and that the range XY is R feet. It is required to find if Y is visible from X. Examine the contours, and decide which intervening crest is likely to impede the view. Measure the range to the crest and also to Y, at the same time noting the contour of

each. Suppose the crest is x yards from X and y feet lower.

Then in x yards the line of sight drops y feet.

$\therefore$ in 1 yard the line of sight drops $\frac{y}{x}$ feet.

$\therefore$ in R yards ,, ,, ,, $\frac{xR}{y}$,,

This gives the amount which the line of sight drops in the range XY. It is easy, therefore, to see if the line of sight from X to Y passes above or below Y, of which the contour is known. If below, Y is visible from X, if above it is not visible. Similarly, if X is lower than Y, calculate how much the line of sight rises to an intervening crest and also in the whole range. If the line of sight passes below Y the two points are mutually visible, if above they are invisible.

Example. X is on a 400-feet contour.
Y ,, ,, 300-feet ,,

The distance from X to Y is 2500 yards.

The crest is 1000 yards away from X on a 350-feet contour.

Is Y visible from X?

Solution. The drop in contours from X to the crest is 50 feet.

In 1000 yards the line of sight drops 50 feet.

$\therefore$ in 2500 ,, ,, ,, ,, 125 ,,

Thus, when the line of sight which starts at the 400-feet contour has travelled as far as Y it is 125 feet lower, and is consequently at the 275-feet contour. Since Y is on the 300-feet contour the line of sight drops below Y. Therefore X and Y are mutually visible.

Modification of Method. Calculate the rise or fall of

the line of sight for the distance between X and Y. Note the difference in height of X and Y. Then, if the line of sight rises more or drops less than the difference in height of the two places, X and Y are mutually invisible.

Example. X is on a 300-feet contour.
Y „ „ 400-feet „

The distance from X to Y is 2000 yards.

The crest is 800 yards away from X on a 350-feet contour.

Is Y visible from X?

Solution. The difference in height between X and Y is 100 feet.

The difference in height between X and the crest is 50 feet.

In 800 yards the line of sight rises 50 feet.
In 2000 „ „ „ „ 125 „

Thus the line of sight rises more than the difference in height of X and Y. Therefore X and Y are mutually invisible.

4. **Comparison of Gradients.** Find the gradient from the lowest point to an intervening crest and from the lowest point to the highest point. If the gradient to the crest is steeper than the gradient to the far point the line of sight to the far point strikes the crest, with the result that the points are mutually invisible.

Example. X is on a 300-feet contour.
Y „ „ 400-feet „

The distance from X to Y is 800 yards.

The crest is 300 yards from X on a 350-feet contour.

Is Y visible from X?

Solution. The gradient from X to the crest

$$= \frac{50}{900} = \frac{1}{18}.$$

The gradient from X to Y

$$= \frac{100}{2400} = \frac{1}{24}.$$

As X is the lowest point, and the gradient from X to the crest is steeper than that from X to Y, the points are mutually invisible.

Modification of Method. Find the gradient from the lowest point to a crest and from the crest to the highest point. If the gradient from the lowest point to the crest is the steeper the two points are mutually invisible.

Example. X is on a 450-feet contour.

The crest is 440 yards from X on a 400-feet contour.

Y is 330 yards from the crest on a 375-feet contour.

Is Y visible from X?

Solution. The gradient from Y to the crest

$$= \frac{25}{990} = \frac{5}{198}.$$

The gradient from the crest to X

$$= \frac{50}{1320} = \frac{5}{132}.$$

Since Y is lower than X, and the gradient from the crest to X is steeper than that from Y to the crest, X and Y are mutually visible.

5. **Comparison of Angles of Sight.** The angle of sight is the angle between the line of sight and the horizontal plane. From an application of the formula D × H.E. = 57·3 × V.I. the following simple approximation (in minutes) can be found:

$$\text{Angle of sight} = \frac{\text{difference of contours in inches}}{\text{hundreds of yards in range}}.$$

Method. D × H.E. (yards) = 57·3 × V.I. (feet).

$$\therefore \text{D} = \frac{60 \text{ (approx.)} \times \text{V.I. (feet)}}{\text{H.E. (yards)}}$$

$$= \frac{60 \times \text{V.I.} \times 12}{\text{H.E.} \times 36} \text{ degrees}$$

$$= \frac{\cancel{60} \times \text{V.I.} \times 12 \times \cancel{60}}{x\ \cancel{\text{hundreds of yards}} \times \cancel{36}} \text{ minute.}$$

$$= \frac{\text{V.I.} \times 12}{x} \text{ minutes}$$

$$= \frac{\text{difference of contours in inches}}{\text{hundreds of yards in range}}.$$

If the V.I. is in metres substitute 40 (approximate number of inches in 1 metre) for 12. The general result is the same.

It may be an angle of elevation or depression.

The method of testing visibility by angles of sight is on the same principle as that by comparison of gradients. Calculate the angle of sight from the lowest point to the intervening crest and from the lowest point to the highest. If the angle of sight to the crest is smaller than that to the highest point the points are mutually visible.

Example. X is on a 400-feet contour.

The crest is 300 yards from X on a 450-feet contour.

Y is 500 yards from X on a 500-feet contour.

Is Y visible from X?

Solution. The angle of sight from X to the crest

$$= \frac{50 \times 12}{3} = 200' \text{ elevation.}$$

The angle of sight from X to Y

$$= \frac{100 \times 12}{5} = 240' \text{ elevation.}$$

Thus the angle of sight from X to Y is greater than that from X to the crest and is one of elevation. Therefore the points are mutually visible.

Modification of Method. Calculate the angle of sight from the lowest point to the crest and from the crest to the highest point. If the angle of sight to the crest is greater than that from the crest to the highest point the two points are mutually invisible.

Example. X is on a 500-feet contour.

The crest is 800 yards from X on a 450-feet contour.

Y is 300 yards from the crest on a 400-feet contour.

Is Y visible from X?

Solution. The angle of sight from Y to the crest

$$= \frac{50 \times 12}{3} = 200' \text{ elevation.}$$

The angle of sight from the crest to X

$$= \frac{50 \times 12}{8} = 75' \text{ elevation.}$$

Thus the angle of sight from Y to the crest is greater than that from the crest to X, and the angles are of elevation. Therefore the points are mutually invisible.

EXERCISES

1. X is on a 400-feet contour while Y is on a 600-feet contour. Three-quarters of the distance between X and Y there is a crest 500 feet high. The distance between X and Y is 4000 yards. Decide, by comparison of gradients, if X can be seen from Y.

2. The angle of sight from X to a crest is 30′ elevation. Beyond

the crest, at a distance of 500 yards, there is a church 25 feet higher than the crest. Can an observer at X see the church?

3. X is on a 600-feet contour. A crest 75 feet lower is at a distance of 500 yards. Can an observer at X see a man 1000 yards distant at Y, the 400-feet contour?

4. A man is standing on a hill 300 feet high. At a distance of 500 yards there is another hill 400 feet high. Can he see a point Y, 650 feet high and 1000 yards beyond the second hill?

ANSWERS

1. The gradient from X to the crest $= \frac{100}{9000} = \frac{1}{90}$.

The gradient from X to Y $= \frac{200}{12000} = \frac{1}{60}$.

X is visible from Y.

2. The angle of sight from X to the crest = 30′ elevation.

The angle of sight from the crest to the church $= \frac{25 \times 12}{5} = 60'$ elevation.

The church is visible from X.

3. In 500 yards the line of sight drops 75 feet.
In 1000 yards the line of sight drops 150 feet.
The difference in height between X and Y is 200 feet.
The observer cannot see the man.

4. The gradient from the 300-feet contour to the 400-feet contour $= \frac{100}{1500} = \frac{1}{15}$.

The gradient from the 300-feet contour to the 650-feet contour $= \frac{350}{4500} = \frac{1}{13}$ (approx.).

The man can see the point Y.

CHAPTER XI

FINDING TRUE NORTH

It is important to be able to fix in the field the direction of the meridian, or geographical north-south line, at any place on the earth's surface. It may be ascertained in various ways:

1. By compass.
2. By observation of the sun.
3. By a watch.
4. By equal altitudes of the sun.
5. By the Pole Star.

1. By Compass

If the variation of the compass at a place is known to be $12\frac{1}{2}^\circ$ west, the true north direction can be found by drawing a line to the right of the north compass direction at an angle of $12\frac{1}{2}^\circ$ with it.

2. By Observation of the Sun

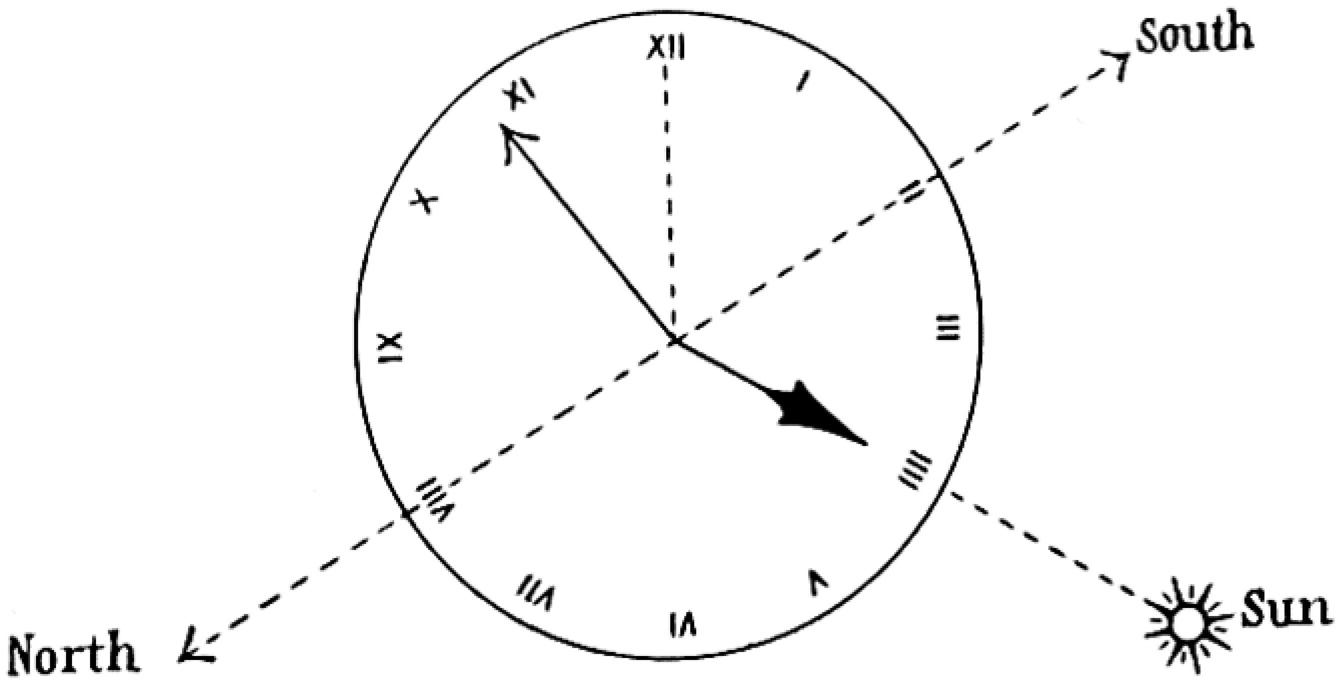
In the Northern Hemisphere the sun approximately rises east and sets west. At 9 A.M., for example, it is roughly south-east, at noon, by a watch, south, and at 3 P.M. south-west. In the Southern Hemisphere, while the sun rises and sets as above, at 9 A.M. it is roughly north-east, at noon north, and at 3 P.M. north-west. Only at two periods of the year, the equinoxes—about March 21 and September 23—does the sun rise due east and set due west.

3. By a Watch

This very convenient but more or less rough method, familiar to scouts, of finding the direction of north by day is based on the assumption that at noon by a watch the sun is on the meridian.

In the Northern Hemisphere

Place a watch horizontally face upward on the palm of the hand, and turn it round, if necessary, till the



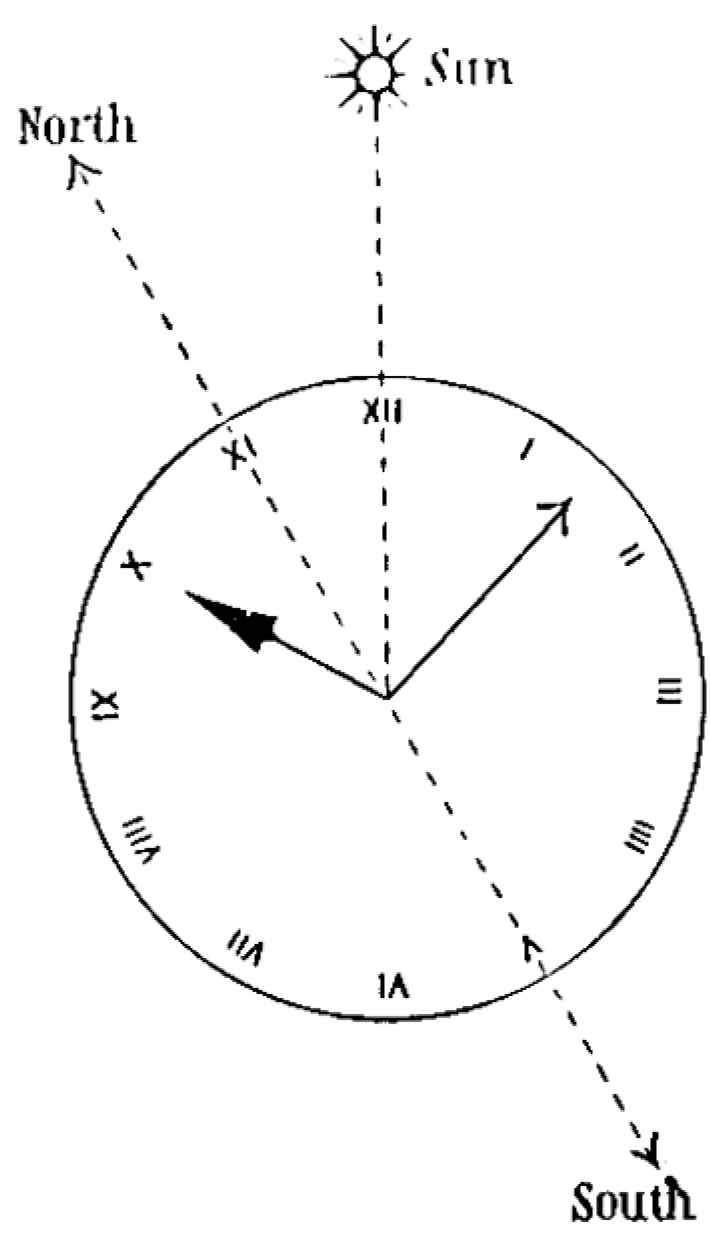
hour hand points toward the sun. Then the bisector of the angle formed by the hour hand and a line drawn from the centre of the dial to the figure XII points to the south.

Application. At 4 P.M., for example, the figure II will point approximately south and the opposite figure, VIII, north. This follows from the fact that at twelve o'clock, if the watch be set to the hour of the place, the sun is due south. Therefore, supposing the figure XII to be turned toward the sun at noon and the watch left in the horizontal position till four o'clock, the hour hand will have travelled twice as fast as the sun, because it makes a complete revolution in twelve hours, while the sun, with an apparently similar movement from

east to west, takes twenty-four hours to complete its circuit. In consequence, the distance of the sun from south at 4 P.M. is measured by half the arc of the dial between figures IV and XII.

In the Southern Hemisphere

In this case, instead of the hour hand, the line joining the centre of the dial to the figure XII is pointed at the sun. The bisector of the angle between this line and the hour hand points to the north.



Note. (*a*) The watch method is most reliable in the higher latitudes—as far as possible from the equator.

(*b*) Since the angle between the lines joining the centre of the dial to any two consecutive hour marks on the dial is 15°, a watch may be used to plot approximate bearings.

(*c*) When summer time is in use the watch must be put back one hour before the method is applied.

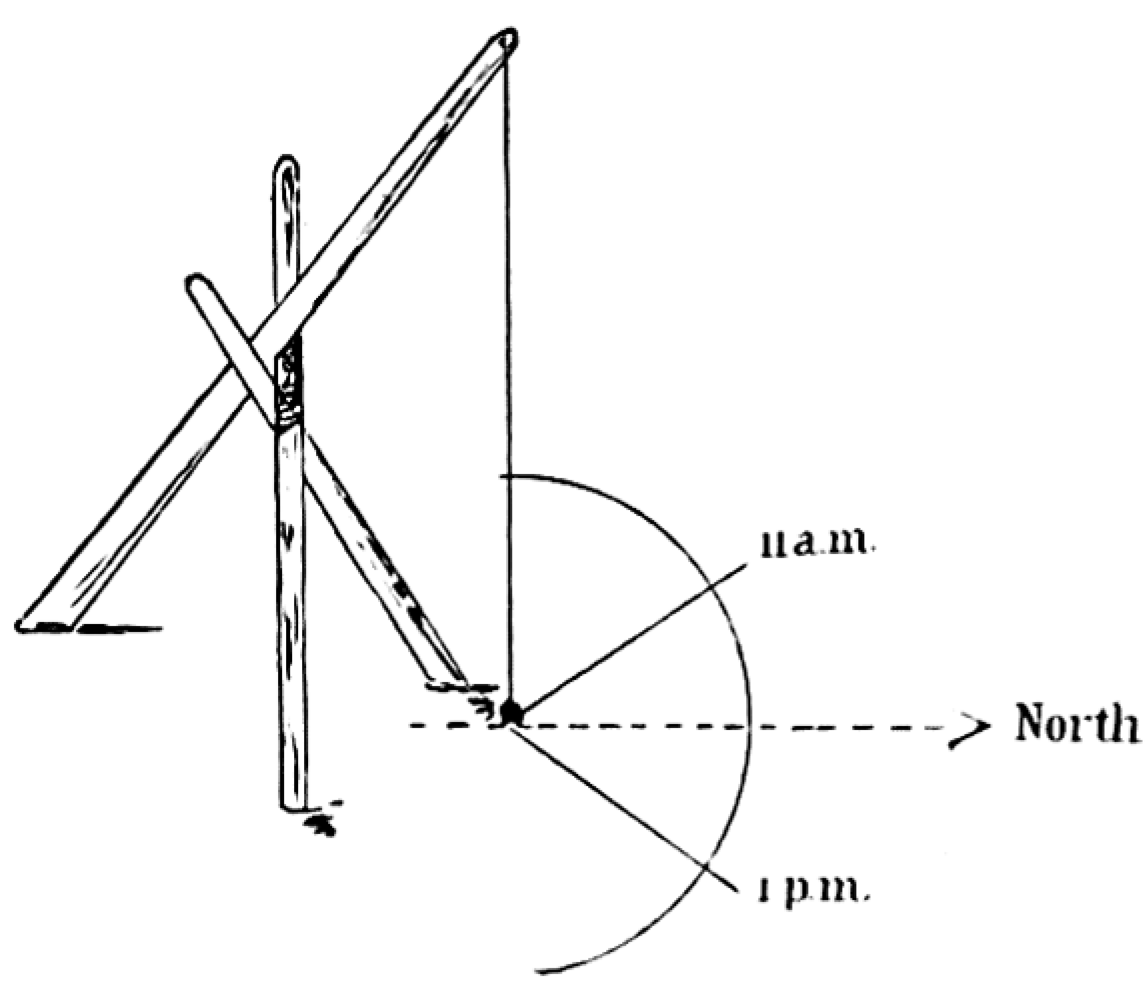
4. By Equal Altitudes of the Sun

An approximate true north line can be found by the observation of shadows cast by the sun. At equal altitudes the sun casts shadows of equal length. At its greatest altitude, or culminating point, when the direction of the shadow is true north in the Northern

Hemisphere the moment of culmination is taken as noon—twelve o'clock by a watch. This time—local mean noon—may differ by as much as twenty minutes from local apparent or true noon, when the sun is on the meridian, and only by the aid of astronomical instruments can the moment of transit be accurately determined. At noon by the watch, therefore, the sun may be considerably off the meridian. Most countries now employ a standard time based on some particular meridian for use on telegraphs and railways throughout the country. For Great Britain the meridian adopted is that of Greenwich.

It is possible, however, in a practical way, without special instruments, to get a more or less accurate idea of the north direction.

Fix a pole lightly in the ground in the manner illustrated, with the top pointing roughly northward. The



surface of the ground should be as level as possible beneath the pole. Suspend from the free end of the

pole a plumb line with the weight just touching the ground. With this point of contact as centre and with any convenient radius draw an arc of a circle. A short time before noon mark where the shadow projected by the pole first cuts the arc. The shadow will gradually become shorter, after which it lengthens again. Mark the point where it again cuts the arc. This must be at the same time after noon as the first point was before noon, for the two marks represent equal altitudes of the sun. Between the two points the sun must have reached its highest point in the heavens. Therefore the bisection of the arc between the two points is true north of the centre.

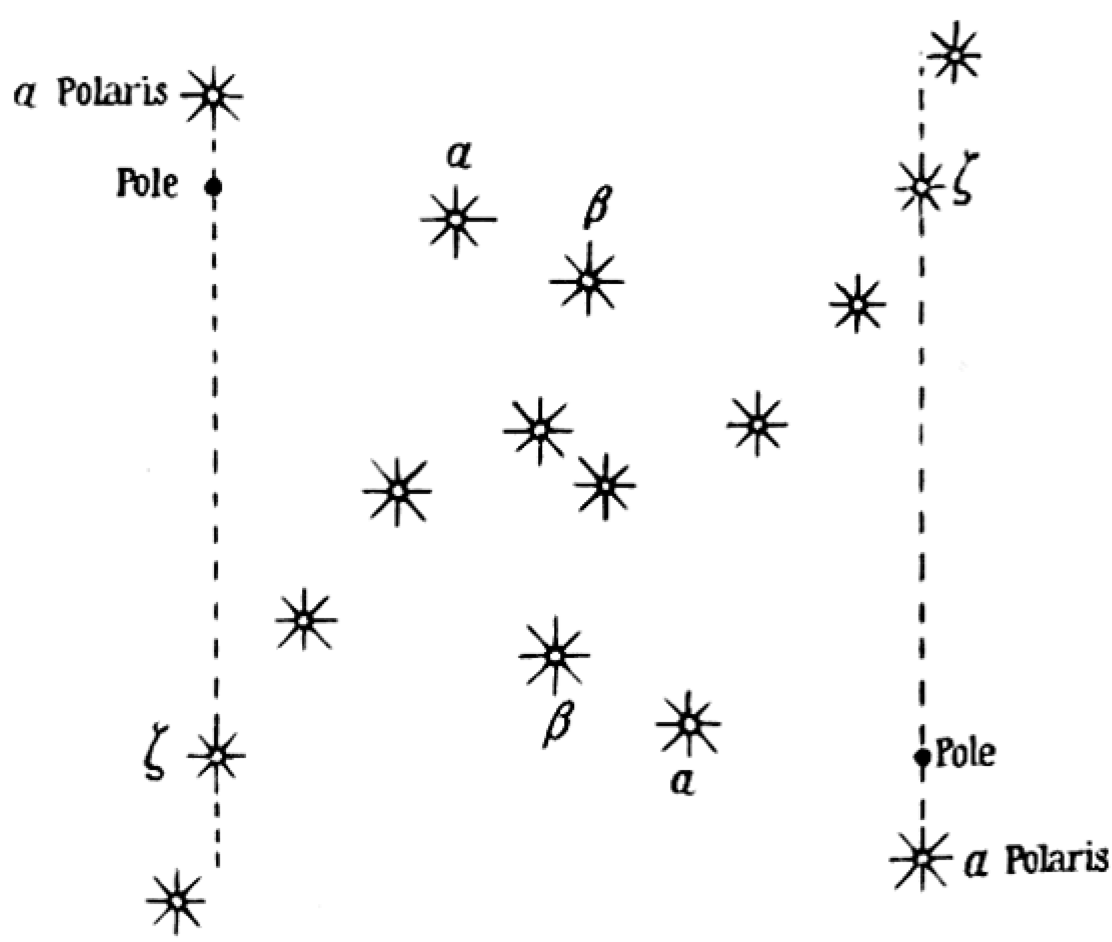
5. By the Pole Star

In the Northern Hemisphere

At night, if the sky be clear, the following method furnishes a simple means of ascertaining, without the necessity of special instruments, the direction of the Pole Star, which is almost due north.

At any season of the year there can be seen at night in the heavens a group of seven very bright stars arranged in the form of a quadrilateral (or body) followed by a tail, or handle, of three stars. These are the principal stars of the constellation Ursa Major, or the Great Bear—more familiarly known as the Plough, and otherwise as the Dipper, Charles's Wain, Jack and his Waggon, and David's Chariot. This constellation never sinks below the horizon in Great Britain and is easy to find. In spring, for example, the Plough is almost overhead: in summer to the right of the Pole Star with the handle pointing upward: in autumn, just after dark, low down in the north: in winter, about

nine o'clock in the evening of late December, to the right of the Pole Star with the handle pointing downward. The two front body stars α (*alpha*) and β (*beta*) are the brightest and are called the *Pointers*, because the prolongation of a line joining them reaches the bright star α Polaris (the Pole Star), which is the last star in the tail of the constellation Ursa Minor, or the Little Bear —of similar shape to the Plough and also containing



seven principal stars. This group is nearest to the north pole. The distance from the nearest Pointer to the pole is nearly the same as the total length of the Plough.

Once in slightly less than twenty-four hours of mean time, by an apparent turning or circling caused by the revolution of the earth, all the stars appear to revolve round the pole. The group composing the Plough may be above or below or right or left of the Pole Star, but always they are at the same distance from it. The Pole Star, which is at present about 1° 5′ distant from the pole, moves round it in a very small circle, so that it is always very close to true north, twice in every twenty-

four hours being exactly true north and coming into the same vertical plane either above or below. Its nearness to the pole causes it to appear to move very little. If, therefore, a bearing were taken of the Pole Star it would really be the bearing of the pole itself. The Pole Star is in the same vertical plane as the pole when the star ζ (*zeta*), last but one in the Great Bear, is in the same vertical plane with it and either above or below. The Pole Star is then on the meridian, and at this instant its bearing should be observed with the prismatic compass.

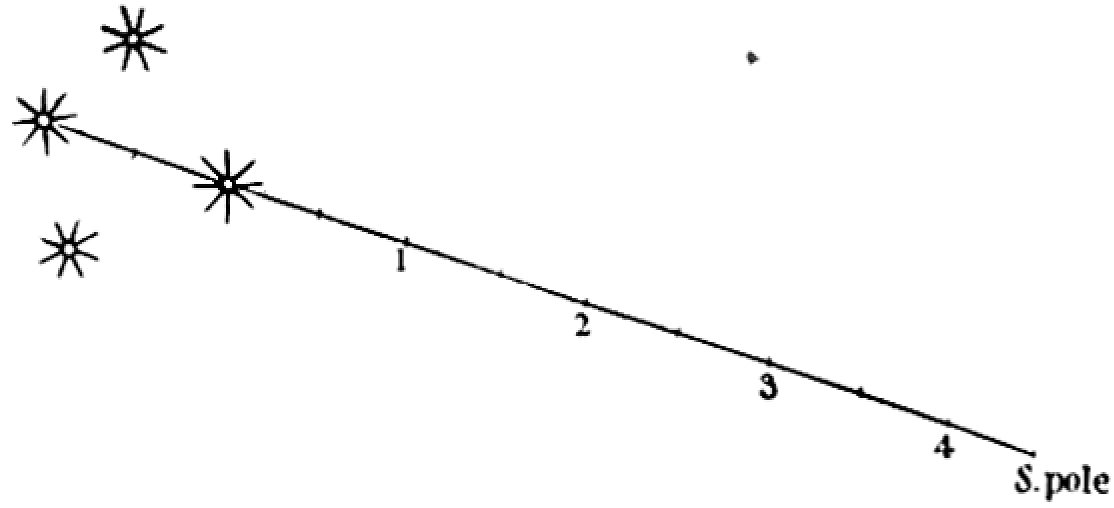
Note. (*a*) At midnight about the beginning of September the Pointers are on the meridian directly under the Pole Star. At 3 A.M. they make an angle of 45° with the vertical, at 6 A.M. they are at right angles to it, and at noon are on the meridian above the Pole Star. They pass the same points four minutes earlier each day until, about the beginning of March, they are directly above the Pole Star at midnight and below it at noon. Thus, knowing the angle the Pointers make at midnight, one may make a rough estimate of the time.

(*b*) The Pole Star varies—it is now about 1° 5′ from true north. In about 150 years α Polaris will be too far away to serve as Pole Star. Several thousand years ago α Draconis occupied the position; 12,500 years hence α Lyrae (Vega) will become the Pole Star.

In the Southern Hemisphere

The constellation known as the Southern Cross is used to find the direction of the true meridian. It is approximately true south when its longest limb is vertical. At other times this constellation is about 30° distant from the southern celestial pole.

Consider the Southern Cross as a kite, and imagine the major axis of it to be produced four and a half times its own length in the direction of the tail. The point reached will be approximately over the south pole of



the heavens. When this is found the major axis of the constellation should be vertical.

Practical Application. Mark off along the edge of a piece of paper twelve lines or points at equal distances apart, thus giving eleven equal divisions. Then hold the paper so that the first and third lines or points coincide with the head and tail stars of the constellation respectively. The twelfth line or point will then give the approximate south point.

Or hold a piece of paper up, and note where the head and tail stars cut the edges of the paper. Bisect this line and produce nine such divisions. The ninth will be approximately over the south pole.

Practical Hints

(*a*) Moss usually grows on the north side of trees.
(*b*) Trees growing on a wall usually face south.
(*c*) Flowers turn their heads toward the sun.
(*d*) The chancel of a church usually looks toward the east.

EXERCISES

1. Give the variation of the compass: (*a*) when the bearing of the sun at noon is 185°; (*b*) when the bearing of the Pole Star is 348°.

2. What is the bearing of the sun at 3 P.M.? (Variation of compass 12½° west.)

3. The variation of a compass is 12½° west. What is the magnetic bearing of the sun at noon?

4. Draw the constellation of the Plough, showing ζ (*zeta*) in the same vertical plane with the Pole Star.

If the compass bearing of the Pole Star is then 344° what is the magnetic variation?

5. Describe how to find the approximate direction of true north by observations of the sun.

6. How can you approximately find the north point in the Southern Hemisphere by means of a watch?

ANSWERS

1. (*a*) 5° west; (*b*) 12° east.
2. 237½°.
3. 192½.
4. 16° east.

CHAPTER XII

SETTING A MAP

In order to employ a map with advantage, so that all its details can be recognized quickly and accurately, it is essential that the map should be correctly 'oriented.' When this is done the map is set so that directions on the map correspond with those on the ground which it represents. The true north direction points to the north pole. It is then possible to identify on the ground the various features shown on the map, provided their distance can be found even approximately. Strictly speaking, *orientation* denotes the establishing of the bearing or direction of one's position with reference to the east. In this connexion it is useful to note that the chancel of a church usually faces east. In the previous chapter it was shown how to establish in the field the direction of the north-south line given by the meridians of the map. The map can then be 'set,' or laid in its true direction on the ground. This may be done with or without a compass.

Methods of Map-setting

With Compass

(*a*) On certain maps the conventional sign for magnetic and true meridians is shown on the margin. The magnetic north line, represented by an arrow head, is usually a short one, and consequently it may be necessary to extend it on the map. Then you have simply

to lay the compass on the map over the magnetic north line and, without displacing the compass, turn round slowly map and compass together until the arrow head and the compass needle are pointing in the same direction. The map is then set. In the process care must be taken to ensure that there is no iron near. Adjustments may have to be made for any individual compass errors or for the annual magnetic variation, which may not correspond with the variation given if the date of publication of the map is not recent.

(*b*) Should there be no conventional sign shown for the magnetic and true meridians, a magnetic north line can be drawn on the map. Suppose the magnetic variation is 12° 30′ west. A ray making an angle of 12° 30′ to the left of any vertical sheet line—which on the latest maps is a true meridian—is then set off. The prismatic compass is opened out flat and placed on any meridian so that the hair line of the lid coincides with it. Map and compass are then turned until the compass needle points 12° 30′ west of the meridian. The map is then correctly set.

Without Compass

(*a*) The sun is due south at noon, and changes its position 15° every hour. Its direction in degrees from true north can be set off by protractor according to the time of day. At one end of this line a pencil is placed vertically or a pin stuck in the map, which is then turned round until the shadow is cast over the line. The map is then set by being placed to coincide with the north and south on the ground.

(*b*) When any feature such as a road, railway, river, canal, hedge, is near one's position and can be iden-

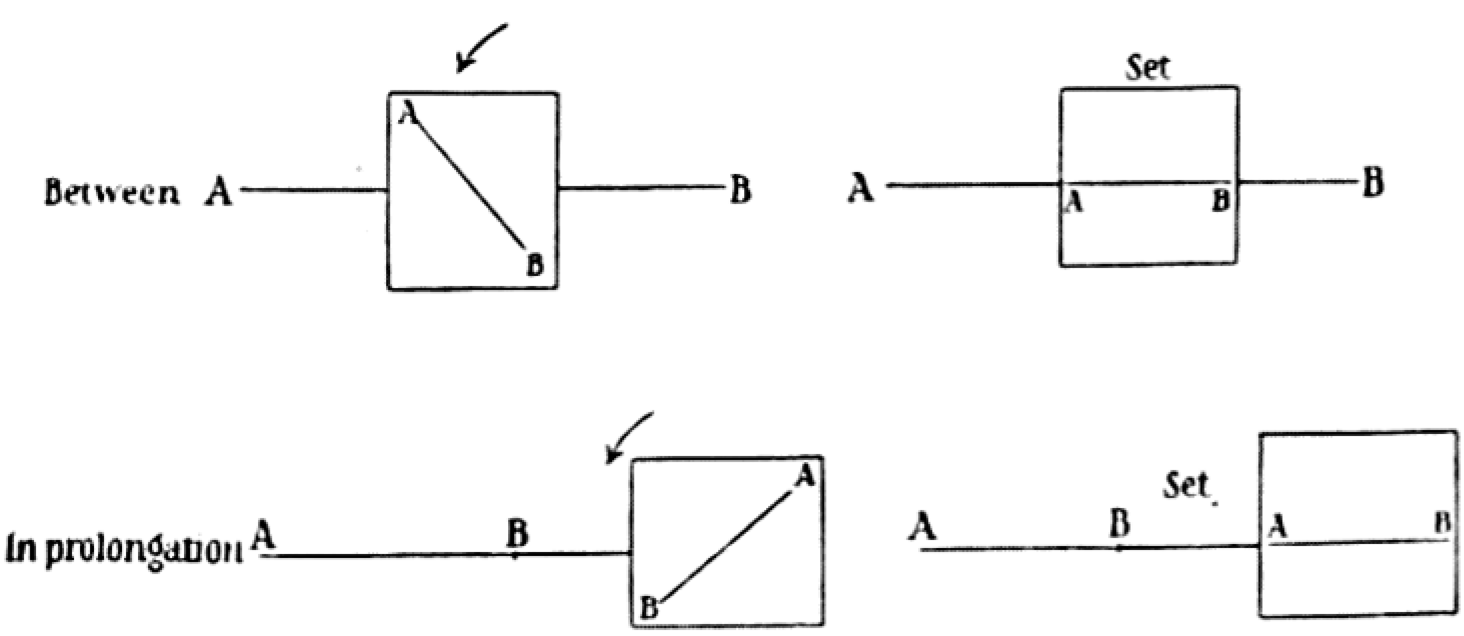
tified on the map, the map can be set approximately if it is turned round until the line of the road, etc., as marked on it is parallel to the line of direction of the actual feature and running in the same direction.

When You can identify your own Position on the Map

Identify your own position on the ground as some point marked on the map. Also identify on the map the representation of some distant object which can be seen. Stick pins in these positions on the map, and then turn it round until they are aligned on the distant object, using the pin in your own position as back-sight. Pins may be dispensed with and the two points on the map joined by a straight line which can be used as a sight-line, or a ruler may be laid between them. The process of setting is then similar.

When You cannot identify your own Position on the Map

Place yourself between or in prolongation of a line joining any two points which can be identified on map



and ground. Then turn the map until the line joining the two marks on it points toward the two positions in

the field. The map is then set. This process is known as 'lining-in.'

When a map is set and one's own position marked, it should be easy to recognize most of the distant features of the landscape. In doubtful or difficult cases a compass bearing can be taken of an object which one wishes to identify on the map. This bearing is then plotted on the map, and at the approximate distance along the direction line search is made until the feature is identified. On the other hand, if a feature on the map cannot be recognized in the field its bearing can be found from the map with the aid of the compass, and so its direction at least can be fixed. With no compass available the same result may be obtained by drawing rays with a ruler, provided the map be correctly set. There may be some difficulty in comparing distances from one's position with distances between the objects themselves owing to the effect of perspective causing an apparent shortening. For example, the distances between objects at an equal range from one's position and actually less than the range may appear considerably greater. With experience the apparent discrepancy can be allowed for.

Typical Problems for Field Work

1. Locate your own position by 'local detail.'
2. Set the map or sketch, using a prismatic compass.
3. Locate your own position by selecting two or more positions on the ground which can be identified on the map (say A, B, and C). Stick a pin in A on the map, and then align another pin on it and its corresponding position on the ground. Draw a line on the map between the two pins. Your own position must be somewhere on it. Repeat the

process with B. Where the two lines or rays cut must be your position. The third object, C, is taken in order that the ray from it may verify the other two. It should pass through the intersection of the first two rays, although a small 'triangle of error' is usual.

4. Locate on the map objects which can be observed on the ground. Their range must be judged or measured by special instrument. Align on the positions with pins, as in 3, using your own position as back-sight.

5. Take a zero line from your own position to some object in the field. Record all the objects visible within, say, 5° or 10° of the zero line. Locate their positions on the map and determine their ranges.

CHAPTER XIII

FINDING POSITION ON MAP

To know one's exact position on the map is an essential preliminary to the accomplishment of useful field work. Very often it is possible to determine it roughly by observations such as to the right of a wood, near cross-roads, to the left of a bridge. For work requiring considerable accuracy such approximations are neither reliable nor sufficient. The following are the various methods of finding one's position on the map:

1. Local detail.
2. Single bearing.
3. Resection: (*a*) with compass; (*b*) without compass.
4. Adjustment.
5. Geometry.
6. Range-finder or combination of range-finder and single bearing.

1. **Local Detail**

It is best to set the map first. Identify as many points as possible in your immediate vicinity on the ground along with their representations on the map. By gauging your distance from these points and your situation with relation to one or two of them you can usually ascertain your position on the map with reasonable precision. This method is most serviceable in country where there are a number of guiding land-

marks—hedges, roads, houses, etc.—but in open or moorland country it will be found difficult to utilize.

2. Single Bearing

You must be on some line which you can identify on the map—*e.g.*, road, river, hedge, or directly between two places. Take a bearing to some distant object, plot the corresponding back bearing from it, and the point at which the back ray cuts the line you are on is your position.

E.g., bearing from road to distant object, 310°.

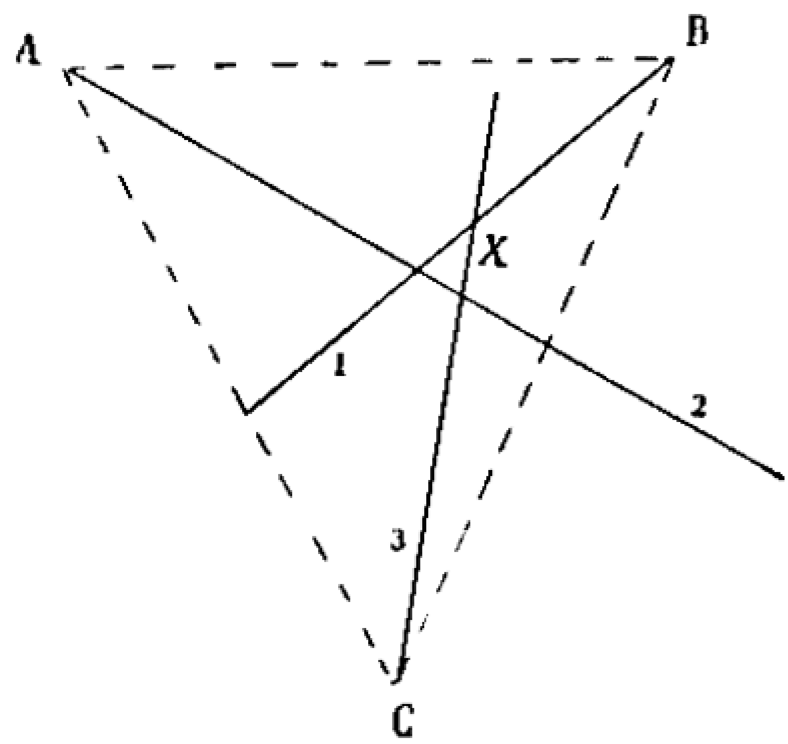
∴ bearing of 130° from representation on map of distant object cuts road on map in your position.

3. Resection

(*a*) **With Compass.** Identify on a map the representations of three recognized objects on the ground. Provided it is easy to take bearings they should be as far distant as possible. Take bearings to each of the selected points in turn, convert into true bearings, and plot the respective back bearings. The rays should be concurrent, the point of intersection, or 'pin-point,' marking your position. Usually, however, they form a triangle called the 'triangle of error.' Apart from possible inaccuracies in observation, the existence of a triangle of error may be due to an error of the compass. If the triangle of error is large it is advisable to revise the work, as a mistake may have been made in plotting a bearing. This can easily be remedied. If the triangle is small your position is determined in the following way.

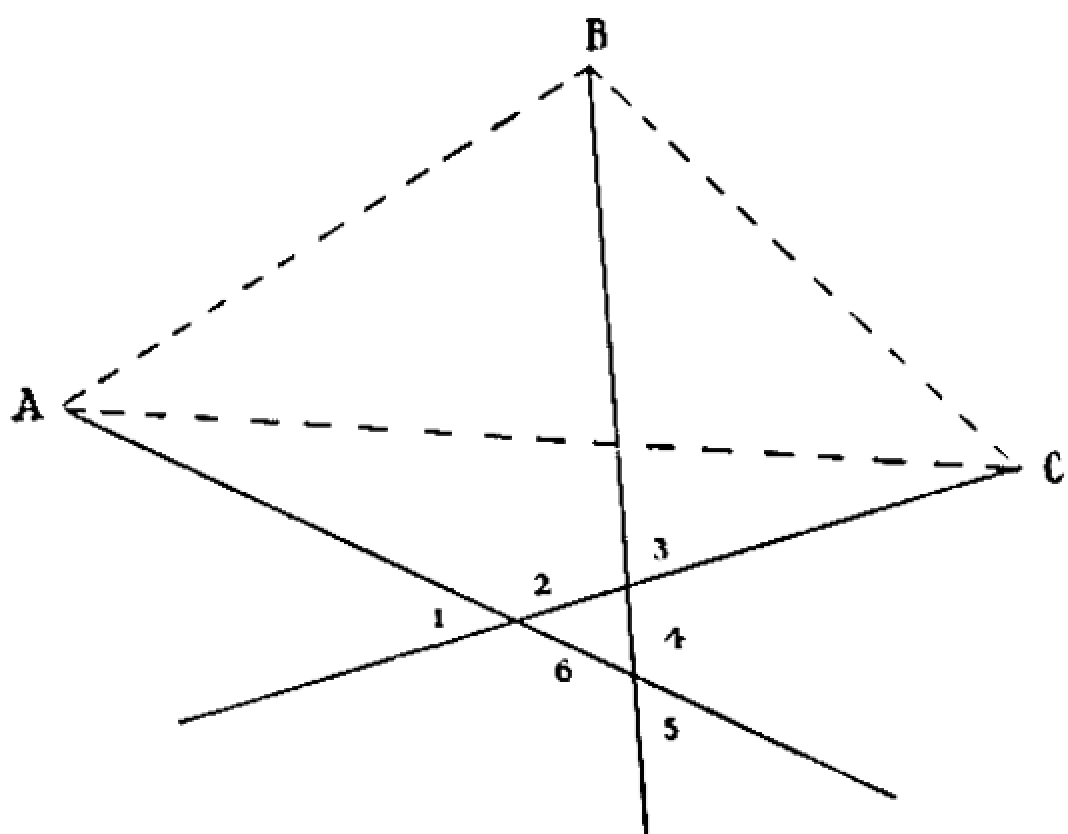
If the triangle of error falls within the triangle formed by joining the three selected points, the position will be within the triangle of error nearest to the shortest

ray, farthest from the longest ray—*i.e.*, within the triangle at distances from each side proportional to the lengths of the rays of which the sides of the triangle form parts.



If the triangle of error falls without the triangle formed by joining the three selected points, the position required is in one of the six sectors formed round the triangle by the three rays. Actually it is in that sector of which all the rays pass either right or left.

If the compass error is *right* (*i.e.*, plus) you cannot be on the right of any ray, which is already too far to the right. Consequently you must be in sector 1, which is left of all the rays, and at a distance from each proportional to its length.



If the compass error is *left* (*i.e.*, minus) you cannot be on the left of any ray, which is already too far to the left. Consequently you must be in sector 4, which is right of all the rays, and at a distance from each proportional to its length.

It is advisable to choose, if possible, three points so placed that you are within the triangle they form. Should the sides of the triangle of error be comparatively large work over again, but if they are very small you may take the centre of the triangle as a sufficiently accurate indication of your position, thereby avoiding much tedious work. In this connexion the scale of the map being used must be considered. On a large-scale map such as 6 inches to 1 mile ·1 inch represents nearly 30 yards, whereas on a $\frac{1}{1,000,000}$ scale ·1 inch represents nearly 3000 yards.

To decide whether the rays pass to right or to left imagine yourself to be standing as nearly as possible facing the points, with either the left-hand or the right-hand side of the body toward the centre of the triangle.

(*b*) **Without Compass.** Set the map carefully. Identify on the ground two, preferably three, distinct, distant, and widely separated objects, at the same time marking their positions on the map. Place a pin on one of these points. Pivoting a ruler against this pin, revolve it until it is aligned on the corresponding distant object. Then a ray drawn along the ruler toward your position should cut it. Repeat the operation for the other point or points, and the intersection of the rays will be your position.

Since no compass error has to be accounted for this should prove an accurate and satisfactory method of resection provided the map is carefully set. If a large triangle of error appears revise the working. If the triangle of error is small your position is practically at its centre.

4. **Adjustment**

A piece of tracing paper only is required. Near the centre of the paper, which is placed on a level surface, mark a point to represent your position. Without disturbing the paper draw rays from the point in the direction of three prominent objects on the ground, the representations of which you can identify on the map. Then apply the tracing paper to the map and adjust it until the rays pass through the three points. The intersection of the rays, which is the point from which the rays were originally drawn, marks your position on the map. In the process of adjustment the rays may have to be produced.

5. **Geometry**

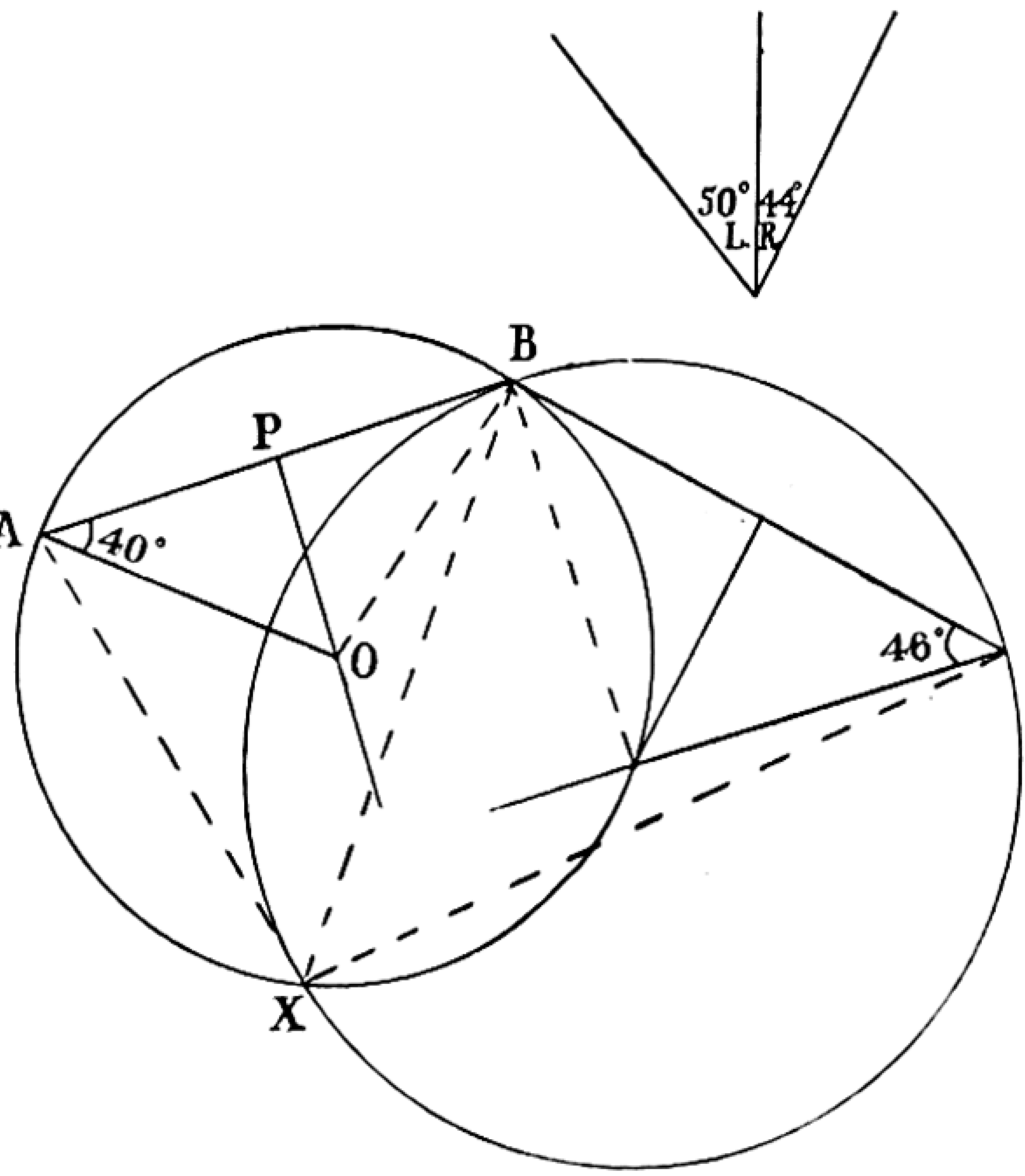
For this method a pair of compasses, a protractor, a prismatic compass, or, if possible, an instrument known as a director, used for measuring horizontal angles, are required.

As in the method by adjustment, select three prominent objects on the ground and mark on the map the points which represent them. Taking the middle object as zero, measure by compass or director 'switch' angles right and left to the other two objects. Then continue the work on the map.

Let A, B, and C be the points on the map, B being taken as zero. The 'switch' angle from your position to A is 50° left and to C 44° right. Join AB and BC. By bearing in mind to which point the angle was *right* and to which *left* you can see roughly in which part of the map your position is. Consider the procedure at 'switch' point A. At this point and on the line AB plot toward your position an angle of 40°, the complement

of the 'switch' angle to A (the sum of complementary angles is 90°).

Bisect AB in P and from P draw PO perpendicular to AB and cutting the line bounding the angle just



plotted in O. With O as centre and OA or OB as radius describe a circle passing through A and B. Repeat the process at 'switch' point C, using the complement of the second 'switch' angle. The two circles thus constructed will intersect at two points: at the zero point, B, and at your position, X.

Proof of Method. $\angle$AOP = complement of $\angle$PAO (geometry) = 50°.

$\triangle$'s APO and BPO are congruent (geometry).

$\therefore$ $\angle$AOP = $\angle$BOP.

$\therefore\ \angle AOB = \text{twice } \angle AOP = 100°$.

But $\angle AXB = \frac{1}{2} \angle AOB$ (angles at circumference and centre of a circle).

$\therefore\ \angle AXB = 50°$ (first 'switch' angle).

Similarly, $\angle CXB = 44°$ (second 'switch' angle).

And since XB is zero line

XA is 50° to the left, and XC is 44° to the right.

$\therefore$ X is your position.

Although the geometrical method is very accurate, provided the 'switch' angles are correctly measured and the construction carefully performed, there is no method of verifying the position as in resection.

6. Range-finder

A special range-finding instrument is necessary. As before, select three prominent objects on the ground and mark their corresponding positions on the map. Take a range to the three objects. With each of the map points as centre and the range (reduced to the scale of the map) to it as radius, describe circles. The intersection of the three circles marks your position. This method is only rough, and the range-finder is of more practical use in locating your position in conjunction with the prismatic compass. Take a bearing to a prominent object, the range of which can be satisfactorily taken. Plot from the map position the back ray, and measure along it the range (reduced to the scale of the map). The point thus reached marks your position.

When a range-finder is used too much reliance must not be placed on it, owing to individual errors in reading range and adjustment.

CHAPTER XIV

TRAVERSING AND PLOTTING

TRAVERSING is a method of making a detailed survey of the ground over which one passes and recording the information obtained in such a way that it can be converted subsequently into a plan or sketch-map. The operation consists in taking a series of forward bearings with the prismatic compass and also measuring the distances between the points from which the bearings are taken. It is a form of survey frequently used for roads and rivers.

Plotting is the process of constructing the plan or sketch-map from the information collected.

To record the information a field book is used. This is a note-book with two parallel lines about half an inch apart forming a column down the centre of each page. The column is called the *chain column*, and contains a record of the route the traverser actually covers, the information about his line of march being entered in it as magnetic bearings and distances. Considered alone, with no outside detail, the chain column affords sufficient data to plot the operator's route. Detail other than that actually traversed is entered at the sides of the chain column as side-entries and offsets, which are measurements taken to objects lying at angles to the traverse line. The points at which roads, railways, rivers, hedges, etc., cross the traverse line are also marked to right and left of the chain column and their bearings given. In each case the distance of the junc-

tion from the point from which the previous bearing was taken should be noted.

The chain column is divided into sectors, each extending from one station or bearing point to the next. In other words, each sector represents one straight piece of road.

As the traverse proceeds prominent landmarks at a distance from the route are sighted and reference bearings taken to them. Their positions can be accurately fixed by bearings taken to them from two or three points on the route, the information being entered as an offset from the chain column at the correct place.

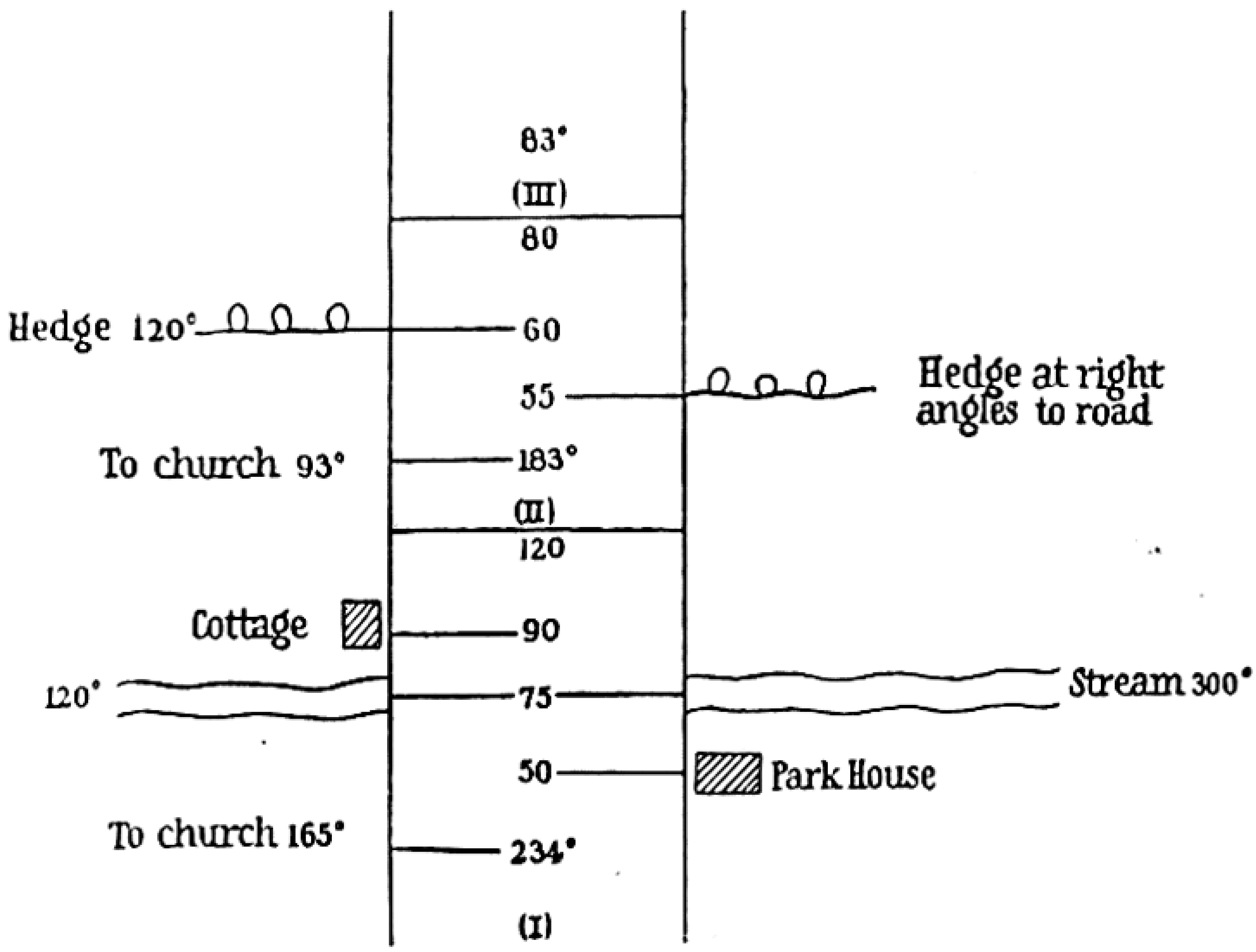
A traverse should begin and, if possible, close at points which have previously been fixed by triangulation. Station lines—*i.e.*, the distances between stations—should be long, giving the traverser an extended line of sight. Distances may be paced or measured by chain, although in this case two operators are necessary, or read from a recording instrument such as a cyclometer.

The diagram on page 124 is a typical example of entries in the field book.

From station (I) there is a church on a magnetic bearing of 165°. The traverser walks from (I) on a bearing of 234° for 50 yards, at which point there is a house on the right of the road. 75 yards from the start there is a stream, the bearings of which on each side of the road are found to be 120° and 300°. 15 yards farther on there is a building on the left. Then after a further 30 yards the direction changes. The first sector closes, and a fresh start is made from station (II).

From this point the church is found to be on a bearing of 93°. The two bearings to the church enable the traverser to mark its position. From station (II) he

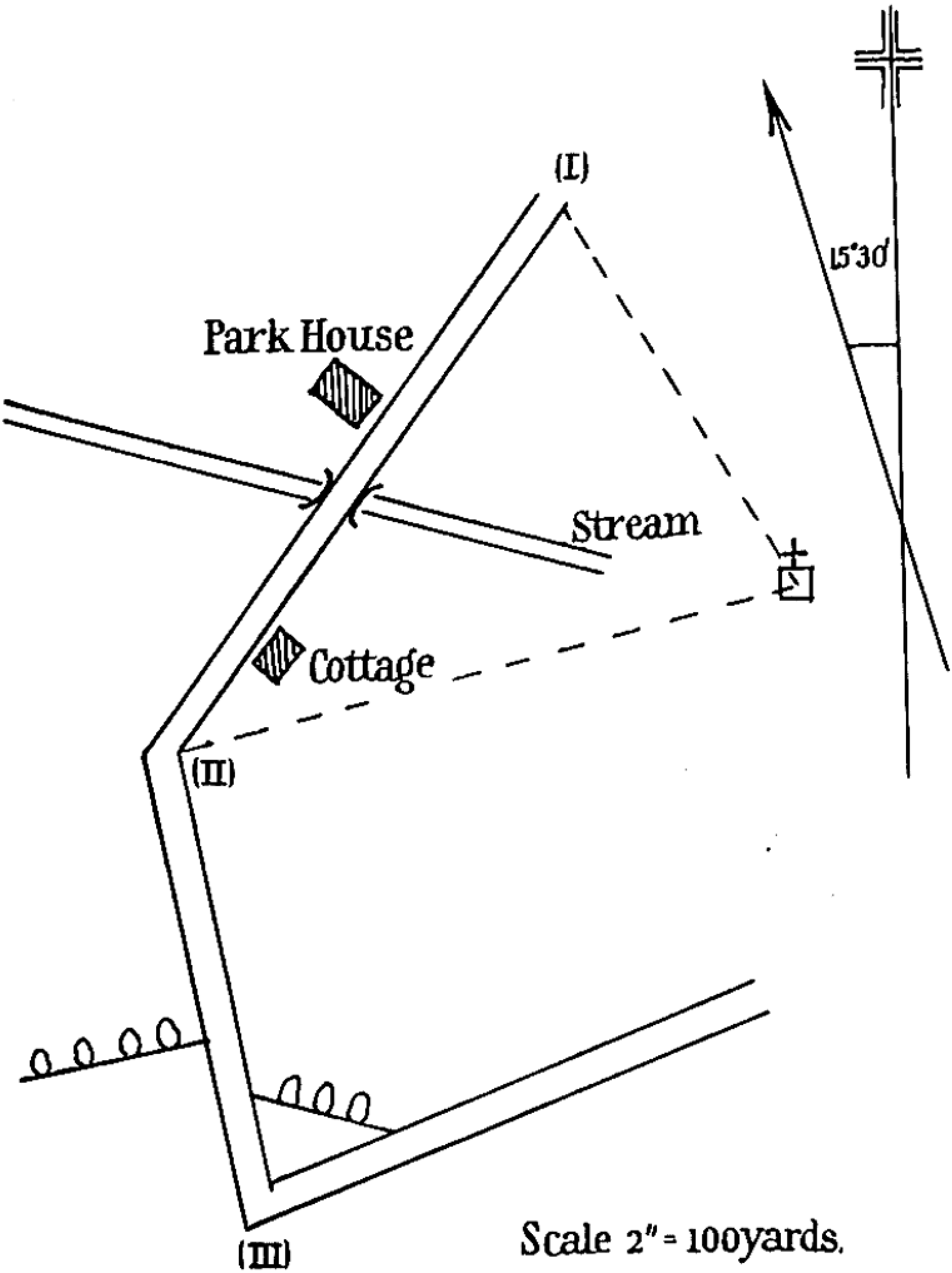
sets out again on a bearing of 183°. After 55 yards he arrives at a hedge on the right of the road and at right angles to it. 5 yards farther on there is a hedge on the left, the magnetic bearing along which is 120°. Finally, 20 yards on the direction again changes, and he arrives



at station (III). From this point he continues on a bearing of 83°, and so on until the traverse is completed.

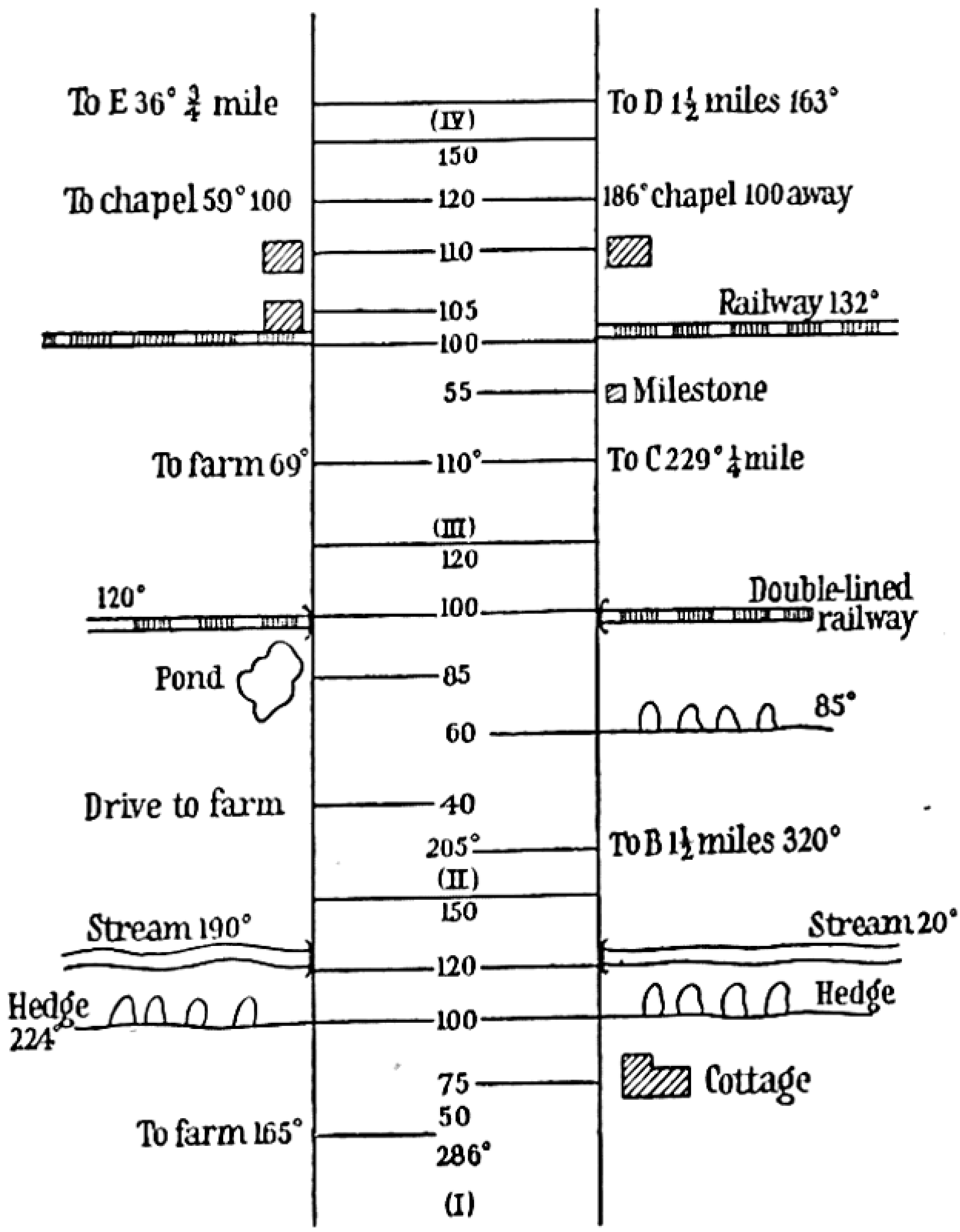
The above information is then converted into a plan or sketch-map.

The plan on the opposite page shows the portion of traverse plotted to a suitable scale. Once the scale is selected the construction of the plan is easy. The general direction of the traverse should first be gauged to decide on what part of the paper the starting-point is to be represented. This will anticipate the possibility of the sketch extending beyond the limits of the paper, which is likely to occur if the position of the starting-point is faulty.

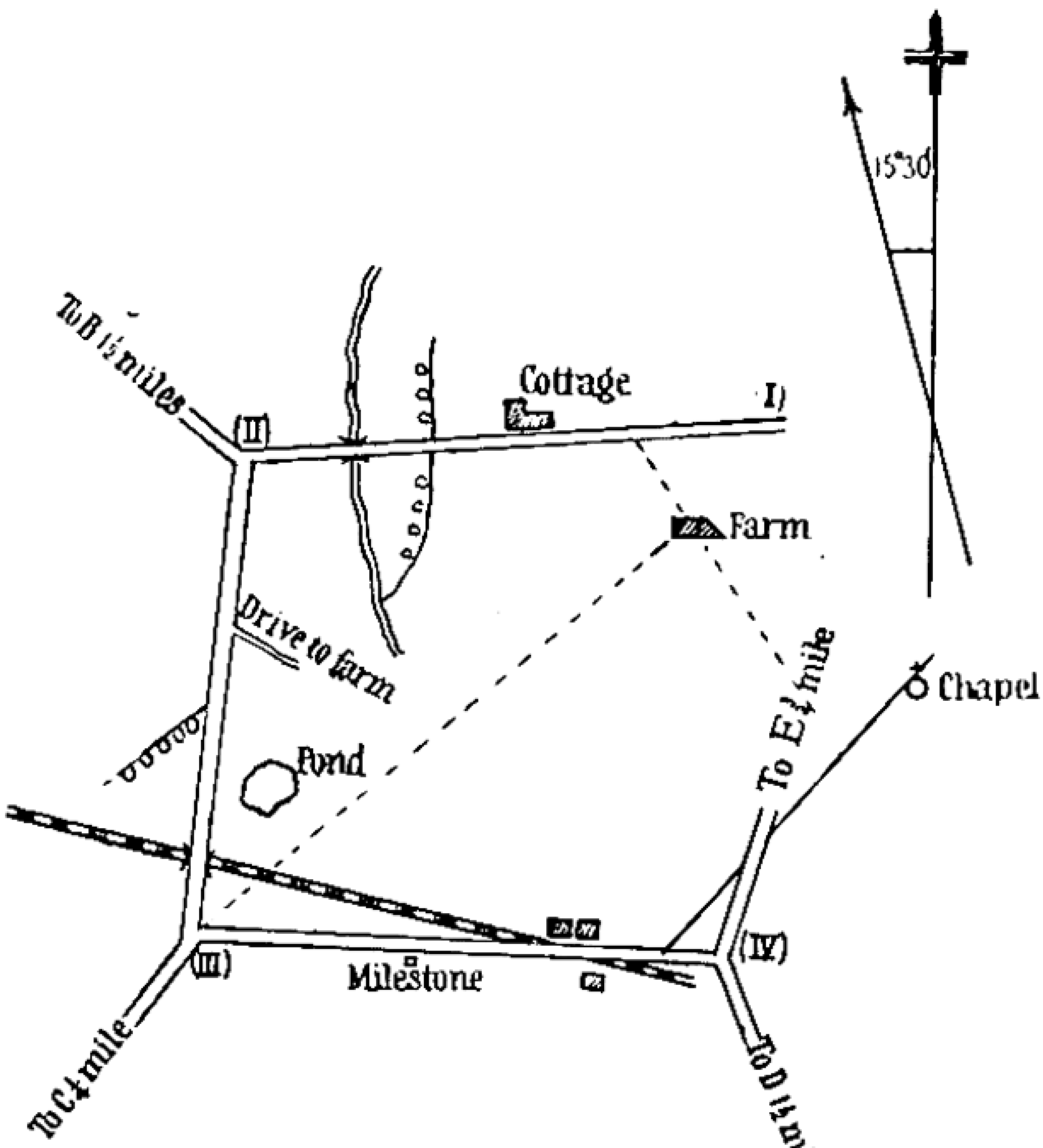


Scale 2" = 100yards.

Example. Plot the following entries from the field book:



Solution.



Scale 1" to 100 yards

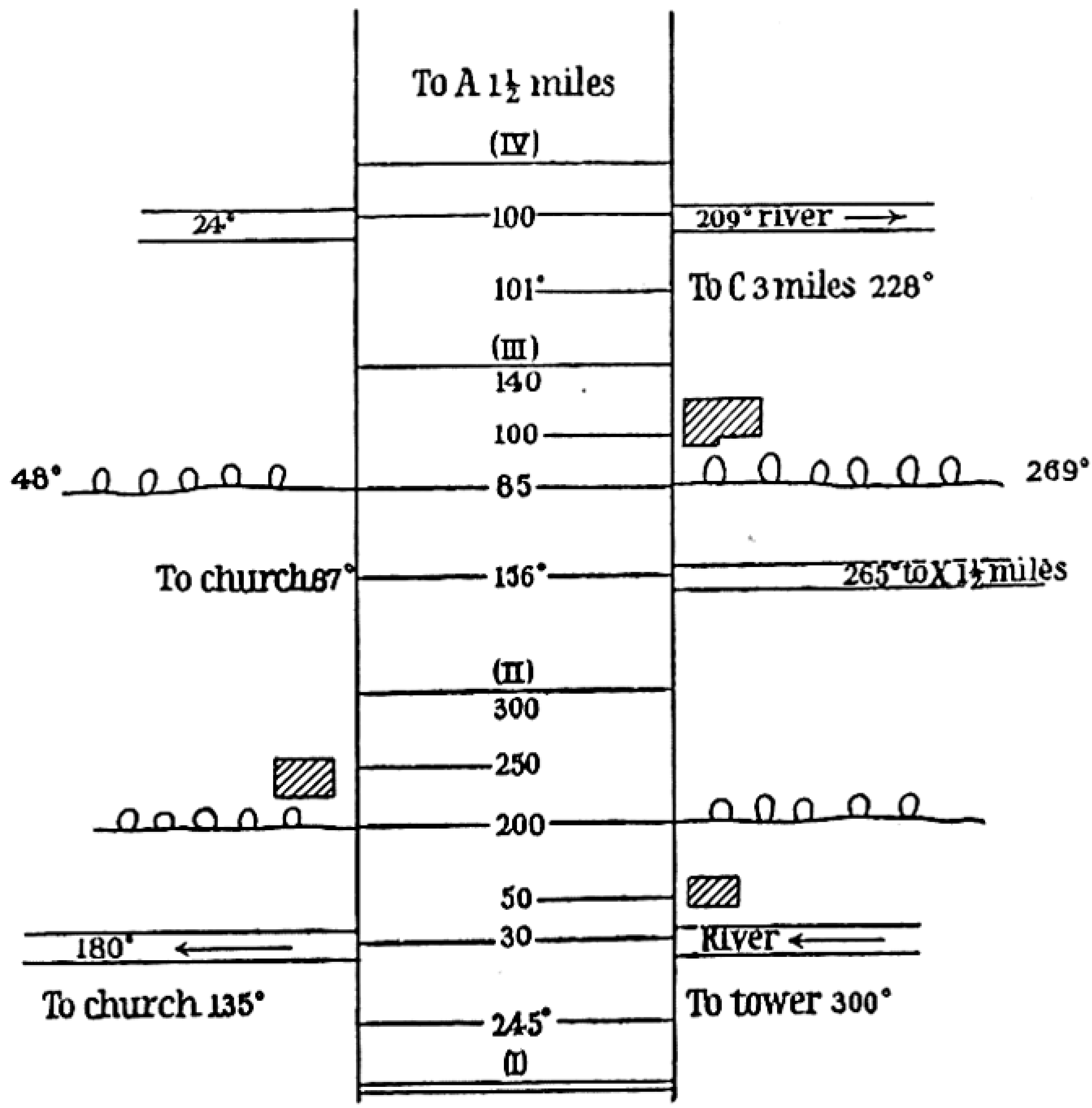
The student should make examples of traverses and plot them for himself, after which he should make an actual traverse along any convenient portion of the road and then plot a plan from the data.

Any departure from the normal method of recording the information is permissible provided the operator intends to construct the sketch-map himself. Otherwise care must be taken that the entries in the field book are thoroughly intelligible and unambiguous.

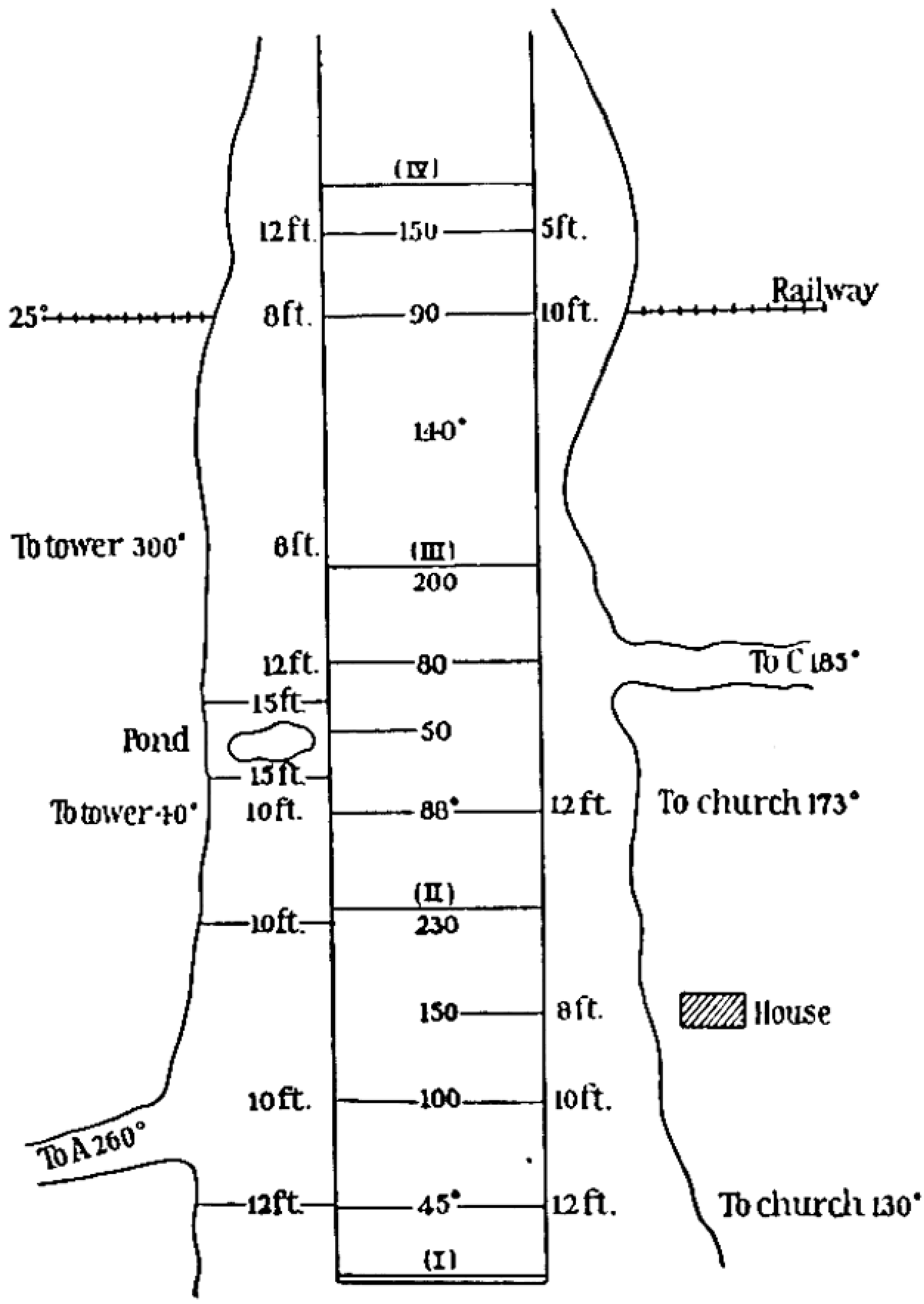
When the traverse is being made along a road the width of which varies considerably, the distance from the straight route to either side should be noted every

few yards alongside the chain column. Example 2 shows a traverse of this variety.

Example 1. Plot the following details of a traverse to a scale of 1 inch to 100 yards.



Example 2. Plot the following traverse to a scale of $\frac{1}{3600}$.



CHAPTER XV

COPYING, ENLARGEMENT, AND REDUCTION OF MAPS

Copying. It is sometimes necessary to make an exact copy of some portion of plan or map. There are various ways of reproducing the map, and the operation, being purely mechanical, presents little difficulty, but requires care.

A fairly accurate result can be got quickly and easily by pinning a piece of tracing paper on the original and pricking through the various features required with a pointed piece of wood. A disadvantage of this method is that in the process the original map is apt to be damaged. It is essential that the work be completed in one operation. Otherwise it is difficult, once the original has been removed, to replace it exactly as it was at first unless guiding marks have been made on the paper.

Alternatively a piece of tracing cloth may be used. This is, of course, much stronger and much more durable, and a well-finished copy can be made on its glazed side.

Probably the most satisfactory method is to use an ordinary piece of carbon paper, which is laid face downward on a sheet of clean paper on which the copy is to be made. The map that is to be copied is then placed face uppermost on top of all. The sheets are pinned together at the corners with drawing pins, and the features that are to be copied are impressed evenly and

firmly with a pencil or pointed piece of wood. On the carbon paper being removed the outlines required are left on the clean paper underneath. To preserve the original from being unduly damaged the plan may first be lightly traced on transparent tracing paper, from which the features are transferred to the clean paper.

Enlargement or Reduction. Map-enlargement is the operation of changing a map or portion of it from one scale to a larger scale. The simplest way to enlarge a map—the process is similar for reduction—is to work by squares.

Certain maps, like military maps, are already divided into squares and can be very conveniently enlarged or reduced. Ordnance Survey maps and others should be divided into any suitable network of squares. Then a square or squares, as required, will be made on a sheet of drawing paper to represent the squares to be reproduced on the new scale, proportionately larger or smaller. When the squares are correctly marked on the drawing paper the details are carefully transferred square by square with light pencil lines. A beginning is best made with features such as railways, roads, or rivers. The drawing is done by eye as accurately as possible, objects occupying the same relative positions in the new squares as in the original. If necessary, the eye may be assisted by subsidiary, faintly indicated squares. Contour lines and spot-heights should be shown in their correct places, but the purpose of the map will determine whether boundary lines be inserted or not. The scale will be shown at the foot, and the true and magnetic meridians should also be marked. Form lines can be interpolated between contours if necessary.

The position of any point in a square may, of course, be obtained accurately by the co-ordinate method and transferred with the same co-ordinates on to the new map. This method is most likely to prove useful in enlarging a military map from, say, $\frac{1}{20,000}$ to $\frac{1}{10,000}$, when you will in all probability be using a protractor which is provided with a means of reading co-ordinates on both scales.

The only calculation necessary in the work of enlargement or reduction is to find the size of the square required on the new scale to represent the square on the original. Where much copying has to be done, as in survey offices, enlargement and reduction of plans are done by photography or by an instrument called a pantograph.

Examples of Enlargement

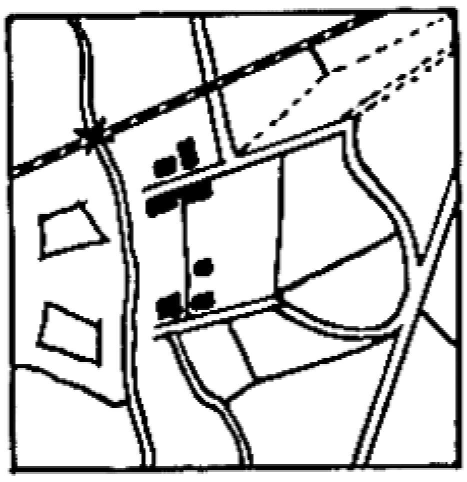
1. It is required to enlarge a portion of a 1 inch to 1 mile Ordnance map to a scale of 3 inches to 1 mile.

Squares of 1-inch side are drawn on the map to cover the portion to be enlarged. Then a series of squares of 3-inch side are drawn, each to correspond with a 1-inch square on the original.

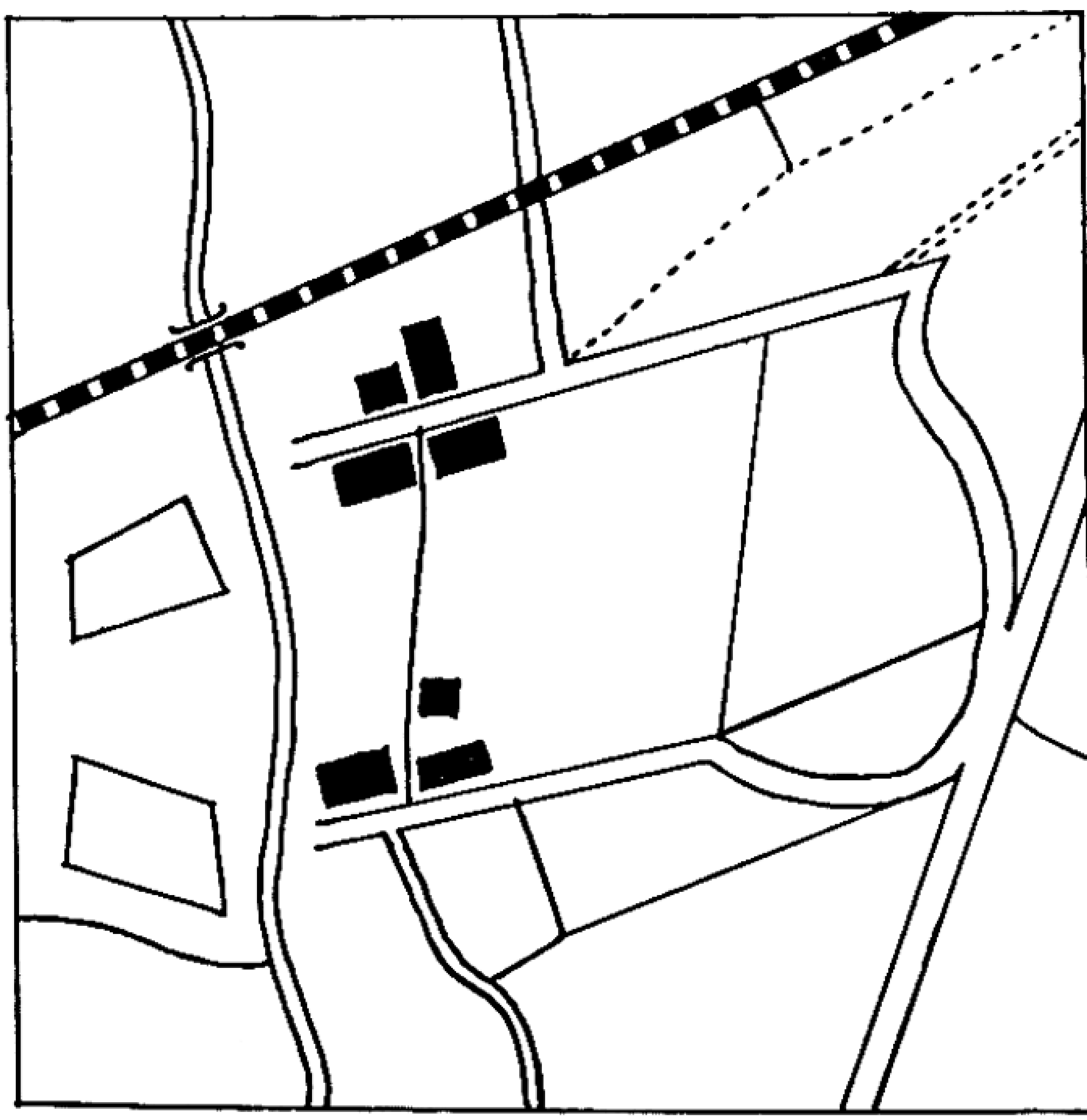
2. It is required to enlarge a portion of a $\frac{1}{20,000}$ map to a scale of $\frac{1}{8000}$.

$$\frac{\text{New scale}}{\text{Old scale}} = \frac{\frac{1}{8000}}{\frac{1}{20,000}} = 2\tfrac{1}{2}.$$

Thus the portion of map is to be enlarged $2\frac{1}{2}$ times.



1″ to 1 mile.



Enlargement 3″ to 1 mile.

Squares will therefore be constructed with sides two and a half times as long as the sides of the map squares they represent.

E.g., 1·8 inches on a $\frac{1}{20,000}$ scale represent a length of 1000 yards.

$\therefore$ on a $\frac{1}{8000}$ scale $1{\cdot}8 \times 2\frac{1}{2}$, or 4·5, inches represent the same length.

EXERCISES

1. Enlarge a square of a $\frac{1}{20,000}$ map to a scale of $\frac{1}{9000}$.

2. Enlarge a square of a $\frac{1}{20,000}$ map to a scale of 6 inches to 1 mile.

ANSWERS

1. Side of 1000 yards square 4 inches (approximately 2·2 times present length).
2. Side of 1000 yards square approximately 3·4 inches (approximately 1·9 times present length).

CHAPTER XVI

AERIAL MAP-READING

An important function of an aeroplane is observational work or reconnaissance of country which is only possible from the air. Nowadays, in addition, aeroplanes are much used for commercial enterprises. An airman must be thoroughly proficient in reading any map supplied to him. It may be only the fragment of a map of a known piece of country without any indication of the scale, yet the airman must be able, by comparing the respective distances on map and ground between known points, to discover and hence construct the scale for the map. He must be conversant with the methods by which hill features are indicated. If contours are used relative heights can be readily noted. When the airman has made himself familiar with map symbols, is able to identify the different slopes and determine visibility and understand thoroughly the subject of bearings, he should exercise himself in studying the map itself—for example, memorizing certain outstanding features and their relative positions.

It will serve no useful purpose to memorize hills and valleys, since from a height of several thousand feet they appear flat. Very important, however, are such landmarks as railways, towns, rivers, woods, etc., and their relative positions. If these are identified on the map a stretch of unknown country becomes comparatively familiar. Before a cross-country flight heights must be very carefully noted, particularly the highest

point on the route. The difference in height between the starting-point and the highest point to be met gives the 'danger' elevation, and it is necessary to increase this by several hundred feet in order to ensure absolute safety.

E.g., Starting-point, 100′ above sea-level.
Highest point on route, 2000′.
Difference in height, 1900′.

At the highest point, then, an elevation of, say, 2300′–2500′ is ample.

As soon as an airman is familiar with the country in the immediate neighbourhood of his aerodrome he is ready to undertake a cross-country flight. If his preliminary study has been thorough the difficulties of unknown country will be much simplified. The experience will afford a good test of his previous study of map-reading in general. In flat country the test is comparatively easy, but difficulty increases as the country becomes complicated by minor features.

Points to observe for Cross-country Flight

The nature of the country to be crossed must first be studied from the map. For this a well-prepared map with features and landmarks clearly shown is necessary, preferably on one sheet and to a convenient scale, say from 4 inches to 6 inches to one mile. Special maps and charts are now adapted for use from the air both by night and by day.[1] The course of flight must be worked out carefully, compass bearings being taken from point to point, after which the length of the journey can be calculated with the aid of the map-scale.

[1] Such as the Ordnance Survey "Civil Air" edition, England and Wales. Scale, ¼ inch to one mile.

Assuming a certain rate of speed, the approximate time required to accomplish the flight can be ascertained. The approximate time to reach a particular point and also the point at which one expects to be at a certain time can also be calculated. To facilitate this it is customary, after the line of flight has been mapped out and the starting-point and destination joined by a straight line on the map, to divide this line into equal parts, each representing ten miles. Thus, taking the speed of a machine as sixty miles per hour, each ten miles represents a space of ten minutes' time. This method of division is especially valuable in the event of an airman for some reason or other losing his bearings. By consulting his watch he knows how long he has been in flight, and reference to his map will enable him to fix the ten-mile division in which he ought to be at the time and help him to get his bearings again. Either his map or the actual ground should confirm the position of some prominent landmark.

In determining the bearing from one point to another local magnetic attraction, due to the influence of hard and soft iron parts of aircraft, causing the needle to be always deflected from the magnetic meridian, must be allowed for. This deviation is calculated from magnetic north and is supplied from a table which should be in the aeroplane. If this is lacking the deviation must be corrected before a flight is commenced, values being obtained when the aircraft is turned to the principal points of the compass. The process is called 'swinging' the compass, and in actual practice is simply the necessary correction for deviation. The compass should be 'swung' after a machine has been damaged and put together again, as its position in the machine

may be changed and different parts may have been added. Small errors are almost negligible owing to the large extent of country which may come within the scope of an aeroplane.

The total error of the compass needle from true north due to variation and deviation is called *compass error.* To neutralize the effect of deviation magnets may be introduced into a machine.

Examples

(*a*) What is the compass course given true bearing 150°, magnetic variation 12° 13·5′ west, deviation 2° west?

True bearing, 150°.
Magnetic variation, 12° 13·5′ west.
Deviation, 2° west.

$$\therefore \text{compass course} = 150^\circ + 12^\circ\ 13{\cdot}5' + 2^\circ = 164^\circ\ 13{\cdot}5'.$$

Similarly, given an easterly variation and deviation of 12° 13·5′ and 2° respectively:

$$\text{Compass course} = 150^\circ - 12^\circ\ 13{\cdot}5' - 2^\circ = 135^\circ\ 46{\cdot}5'.$$

(*b*) What are the true and magnetic bearings given compass course 250°, magnetic variation 12° 13·5′ west, deviation 2° east?

Compass course, 250°.
Deviation 2°, east.

$$\therefore \text{magnetic course} = 250^\circ + 2^\circ = 252^\circ.$$

Magnetic variation, 12° 13·5′ west.

$$\therefore \text{true course} = 252^\circ - 12^\circ\ 13{\cdot}5' = 239^\circ\ 46{\cdot}5'.$$

(*c*) Given true course 60°, magnetic course 72°, and compass course 70°, find magnetic variation and deviation.

Magnetic course, 72°.
True course, 60°.
∴ variation = 12° west (since magnetic course is > true course).
Magnetic course, 72°.
Compass course, 70°.
∴ deviation = 2° east (since compass course is < magnetic course).

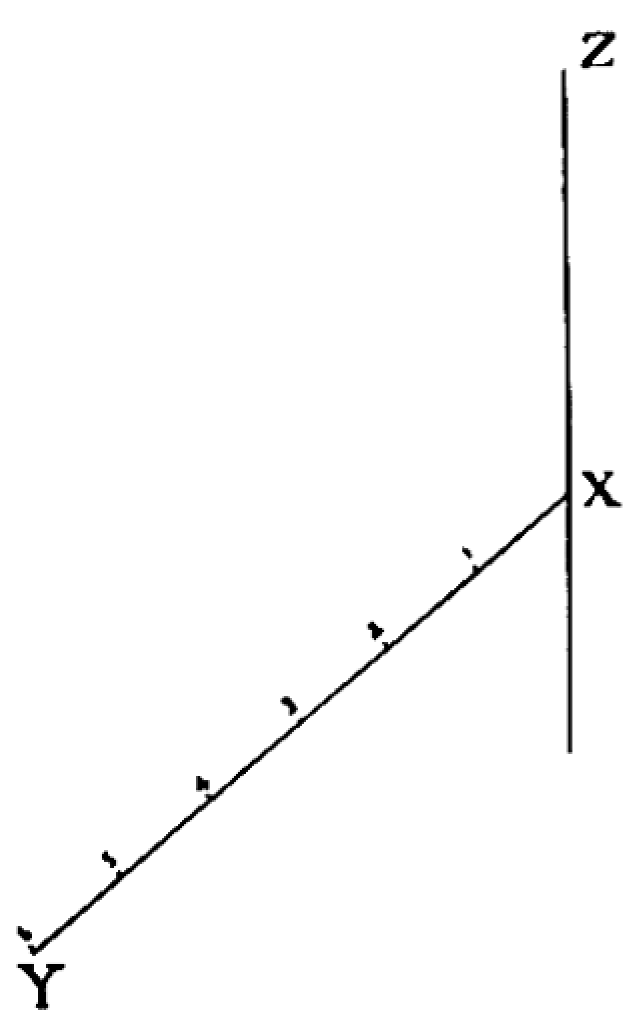
(*d*) Find the true course given compass course 8°, magnetic variation 12° west, deviation 2° east.

Compass course, 8°.
Deviation, 2° east.
∴ magnetic course = 10°.
Magnetic variation, 12° west.
∴ true course = 358°.

Typical Problem. To plot a flight or construct a *time scale* for a journey.

Distance (by calculation), 60 miles.

Let XY represent the distance on the map and XZ the true north line. Divide XY into six equal parts, each representing ten miles, and number them.



Magnetic variation, 12° 13·5′ west.
Deviation 2°, west.
True bearing of Y from X is found to be 230°.

$$\therefore \text{compass course} = 230^\circ + 12^\circ\ 13{\cdot}5' + 2^\circ$$
$$= 244^\circ\ 13{\cdot}5'.$$

Given the rate of the aeroplane to be ninety miles per hour, each division represents $6\frac{2}{3}$ minutes of time. Thus, if starting time be 9 A.M. the time of reaching station 3 is 9.20 A.M. The map used for the journey will probably be a small-scale 'quarter-inch' one, although for certain areas it may be necessary to use large-scale maps. It is useful to memorize the country to be traversed. Prominent objects to be looked for on or near the track are usually enclosed on the map by red circles and should be of distinct and well-defined shape and easily visible. Such landmarks, for example, are rivers and lakes, straight roads (appear light in colour) and road junctions, railways, especially junctions or crossings, peculiarly shaped woods, towns, isolated houses and buildings, especially if on a hill, features of the coast, such as harbours, lighthouses, and distinctively coloured cliffs, lightships and large buoys. The latest weather forecast showing the state of the atmosphere is an important factor in determining the readiness with which features, already visualized by the airman, can be recognized on the ground. A high degree of visibility, ensuring a clear outlook ahead, is essential to the best results. The strength and direction of the winds at various heights is also important.

Mention has already been made of the possibility of an airman losing his bearings and seeking to recover his position by calculation. If this fails he must concentrate his attention on some prominent object on the ground and, keeping in mind his approximate location, try to fix the object on the map. If the day is favourable and visibility good he may be able to descend to a

lower altitude and read the name of some railway station. Failing these resources, it may finally be necessary for him to make a landing and inquire as to his position. If he can get no information he must then have recourse to his map. First of all he must 'set' it and, as local detail has already failed to give him his position, he must make use of the variation at the place to find the true north line. The variation will usually be known approximately. Comparison of map and ground may then enable him to get a rough idea of his position. Finally, he may 'resect' for his exact position.

Essentials of Aviation Maps. The chief requisite of a good aviation map is freedom from too much detail, which is completely lost sight of at a height. A motor map, for example, would be of small value to an airman, as it is generally crowded with every available detail. Only prominent landmarks clearly and accurately marked so that their relative positions can be readily noted are necessary. In the best aviation maps small details are omitted as unnecessary, and a large stretch of country is represented, necessarily upon a much smaller scale than if the country had to be studied from portions of maps of different parts and pieced together. It should be possible for an experienced airman to make full use of peculiarities of local detail, unmarked on the map, as a means of fixing his position.

Aero-photo Maps. The problem of geographical reconnaissance by aeroplane photography, with the ultimate object of utilizing air photographs in the production of maps, is one of very great importance. During the Great War experiments were made in several of the war zones in connexion with the opera-

tions being carried on. Photographs were taken and employed in the production of maps. Large areas were mapped, and the result was of great practical value in the successful carrying out of military plans. The configuration of the ground will determine very largely the use of an air photograph. For rapid reconnaissance of large areas probably the most satisfactory methods can be put to the best advantage in parts where the ground is comparatively flat and at the same time bounded and intersected by features such as trees and hedges. The process is a very slow one for a ground survey of this nature, as a large number of stations have to be occupied, whereas an air survey can be more quickly and accurately made. Even in very flat country, which at the same time is very irregular and broken, the inter-relation of detail is often so complicated that a survey on the ground is impossible, and only an air photograph will show all the detail. In short, photography from the air must be employed only for work for which it is adapted. For example, it has little application to the geodetic aspect of surveying, and is more suitable for medium-scale than for very large-scale or very small-scale maps.

For sketching and for mapping the most useful type of photograph is the vertical, taken during a straight and level flight. This should give as perfect a plan as possible. In practice the camera is always tilted in one direction or another, probably within an angle of two degrees if flying is uninterrupted.

Since rays of reflected light from the area photographed converge in a cone with apex at the lens of the camera the higher a point is the greater will the distance of its image appear from the centre of the photograph.

For accurate mapping it is difficult to rectify the effect of tilt and height distortion. For sketching it is generally sufficient, except in the most mountainous country, to use only points which do not lie much above or below the average level.

One of the most important methods in sketching from air photographs is that of intersections. By the laws of perspective the image of a straight line on any plane appears as a straight line on any perspective of that plane, so that, however tilted the photograph may be, the map position of a point which is able to be identified on the photograph but not on the map will appear on the map at the intersection of the same lines as on the photograph. Sometimes, however, few points can be found common to map and photograph, and without at least four identifiable points reliable work is not possible.

INDEX

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